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ABSTRACT

The document is designed to help map readers comprehend the uses and limitations of maps. Intended predominantly for college students of geography, graphic arts, and public communication, the resource paper should also be of general interest to informed citizens and map enthusiasts. The document is presented in six chapters. Chapter I discusses and defines major elements common to all maps--projection, scale and generalization, and symbolization. Chapter II addresses the process of cartographic communication and identifies factors which influence the successful transfer of a map's message from author to reader. Factors include the cartographer's data, intent, design, and reproduction process, and the reader's understanding, intelligence, biases, and perceptions. Chapter III explores the relationship between map projections and effective communication and describes methods for constructing three nontraditional projections. Chapter IV examines methods for reducing complexity of mapped patterns. Topics discussed include choroplethic maps, classification errors, pattern and perception, cartographic correlation, and information overkill. Chapter V shows how map distortion can serve a variety of goals, such as route planning, data processing, advertising, advocacy, and research. The final chapter presents concluding remarks. A major conclusion is that both map reader and map author should strive to understand the process of cartographic communication. (Author/DB)

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MAPS, DISTORTION, AND MEANING

Mark S. Monmonier
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FOREWORD

In 1968, the Commission on College Geography of the Association of American Geographers published its first Resource Paper, *Theories of Urban Location*, by Brian J. L. Berry. In 1974, coinciding with the termination of NSF funding for the Commission, Resource Paper number 28 appeared, *The Underdevelopment and Modernization of the Third World*, by Anthony R. deSouza and Philip W. Porter. Of the many CCG activities, the Resource Papers Series became an effective means for permitting both teachers and students to keep abreast of developments in the field.

Because of the popularity and usefulness of the Resource Papers, the AAG applied for and received a modest grant from NSF to continue to produce Resource Papers and to put the series on a self-supporting basis. The present Resource Papers Panel subscribes to the original purposes of the Series, which are quoted below:

> The Resource Papers have been developed as expository documents for the use of both the student and the instructor. They are experimental in that they are designed to supplement existing texts and to fill a gap between significant research in American geography and readily accessible materials. The papers are concerned with important concepts or topics in modern geography and focus on one of three general themes: geographic theory; policy implications; or contemporary social relevance. They are designed to complement a variety of undergraduate college geography courses at the introductory and advanced level.

In an effort to increase the utility of these papers, the Panel has attempted to be particularly sensitive to the currency of materials for undergraduate geography courses and to the writing style of these papers.

The Resource Papers are developed, printed, and distributed under the auspices of the Association of American Geographers, with partial funding from a National Science Foundation grant. The ideas presented in these papers do not imply endorsement by the AAG.

Many individuals have assisted in producing these Resource Papers, and we wish to acknowledge those who assisted the Panel in reviewing the authors' prospectuses, in reading and commenting on the various drafts, and in making helpful suggestions. The Panel also acknowledges the perceptive suggestions and editorial assistance of Jane F. Castner of the AAG Central Office.

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PREFACE AND USER'S GUIDE

All maps distort reality. This statement's ramifications are important not only to geographers and map makers, who can and should shape a map's distortion to suit its message and audience, but to the average map reader as well. Almost all people in developed nations are consumers of maps, but they receive little formal training in map reading. Yet, just as consumers of food products and durable goods need to be knowledgeable in their purchases, the map reader should comprehend maps' uses and limitations.

Map use cannot be effortless. Many maps—particularly general as opposed to thematic maps—cannot and should not be distilled into useless sheets of paper for the graphically lazy. Mapped information, like other information, achieves meaning only when the user is both able and willing to study the map. Although map makers should strive for clarity, their goal should be to inform—not to seduce. Both map reader and map author have active rather than passive roles in cartographic communication; both should attempt to understand the communication process; both must strive to make it effective.

This Resource Paper explores the interface between map author and map user. Its aim is to show that, even though maps must inherently "lie" since they cannot convey the entire "truth," a map's "lie" can be an effective "white lie" that permits and encourages the communication of a valid idea.

Chapter One is a condensed discussion of the ingredients common to all maps—projection, scale and generalization, and symbolization—and provides an introduction for later chapters. Chapter Two addresses the process of cartographic communication and attempts to identify factors which either enhance or diminish the likelihood that a map's message will be conveyed successfully from author to reader. Chapter Three concerns the relationship between map projections and effective communication and also describes methods for constructing three nontraditional projections. The applications and pitfalls of choroplethic mapping, one of the most important geographic tools of researchers and planners, are investigated in Chapter Four. A wider range of mapping applications embracing travel, census enumeration, environmental preservation, advertising, counterintelligence and political propaganda are discussed in Chapter Five to show how map distortion can be made to serve a variety of goals.

College courses in cartographic drafting and map design are not necessarily the most efficient means of informing consumers about maps. Even geography majors might be better prepared for an introductory cartography course if exposed earlier in their academic programs to important but less technical cartographic concepts. The author developed "Lure and Logic of Maps," a preintroductory nonlaboratory survey of geographic cartography, to serve both budding geographers and map consumers exercising their "right to know." Material for this Resource Paper is drawn from the third generation of lecture notes for this course, which also includes introductions to remote sensing and topographic map reading.

The Resource Paper can complement a variety of existing texts. Tyner's (1973) *The World of Maps and Mapping* has been a helpful companion. If

(Continued on next page)

surveying and geodesy were to be included, Greenhood's (1964) *Mapping* would be useful. In a laboratory course such standard texts as Hodgkiss' (1970) *Maps for Books and Theses* and Robinson and Sale's (1969) *Elements of Cartography* would be suitable supplements, as would a series of other paperbacks which might include Muehrcke's (1972) *Thematic Cartography*. Should a department's teaching load not permit a survey course devoted solely to maps, this Resource Paper can complement a general text in basic courses on physical, economic, urban, population, or social geography.

Outside geography curricula, this paper can fill gaps currently existing in introductory texts on graphic arts and public communication—fields where necessary geographic skills are usually limited or lacking. In addition, the Resource Paper should be of general interest to informed citizens and map enthusiasts alike.

The Syracuse University Cartographic Laboratory was indispensable in the preparation of this paper. D. Michael Kirchoff, Lab Manager, supervised the production of the figures. Assistants contributing their talent, time, and patience were Jonathan Doughty, Bruce Wands, Karen McCombe, Anne Viront-Lazar, and Karen Guancione. The comments of George A. Schnell on an earlier draft were most helpful. My dedication is to Marge, who admits that maps are to be cherished and has stopped asking, "What is a Resource Paper?"

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CONTENTS

PREFACE AND USER'S GUIDE v
I. ELEMENTS OF A MAP 1
Projection 1
Scale and Generalization 4
Symbolization 5
II. CARTOGRAPHIC COMMUNICATION 9
Major Factors of Map Communication 9
Information Theory 10
A Model of Cartographic Communication 11
III. PROJECTIONS AND PRAGMATISM 15
The Mercator Mystique 15
Area Cartograms 18
Distance Transformations 20
Stepped Statistical Surfaces 22
IV. CLASSIFICATION AND CHOROPLETHIC MAPS 25
Classification Error 25
Pattern and Perception 26
Cartographic Correlation 29
Information Overkill 33
V. PURPOSE AND DISTORTION 35
Route Planning and Route Following 35
Maps For Data Processing 38
Advocacy, Research, and Mapping 40
Maps and Advertising 42
Information and Misinformation 43
VI. CONCLUDING REMARKS 47
BIBLIOGRAPHY 49

LIST OF FIGURES

1. Profiles of developable surfaces and the globe 2
2. Graticules of azimuthal, cylindrical, and conic projections 2
3. Example of loss of detail as a map's scale is reduced 5
4. Examples of map symbols 6
5. Model of a generalized communication system 11
6. Model of cartographic communication 12
7. Poor and good figure-ground differentiation 13
8. President Ford's flight from Washington to Peking, 1975 16
9. Distortion of distance and area on a Mercator projection 17
10. Goode's interrupted homolosine equal-area projection 17
11. Contiguous area cartogram showing worldwide patterns of oil and coal reserves 19
12. Stages in the construction of a contiguous area cartogram 19
13. Reconstruction of the Massachusetts outline by adding rectangles and triangles 20
14. A noncontiguous area cartogram 21
15. Stages in the construction of a distance-transformation map 21
16. Distance-transformation maps focused on Syracuse, New York 22
17. Prism representing population as a volume and population density as its height 22
18. Stepped and smoothed isometric views of Alberta's population distribution 23
19. Stages in the construction of an isometric stepped statistical surface 24
20. Isometric stepped statistical surface of physicians per 100,000 people, New England States, 1967 24
21. Choroplethic representation of a statistical surface 25
22. Influence of class breaks on map pattern 26
23. Number line illustrating some different methods of determining class breaks 26
24. A choroplethic map without class intervals for census tracts in Ann Arbor, Michigan 27
25. Fragmented and simple patterns produced by different classifications of the same data 28
26. Paired maps and a scatter diagram representing the correlation between variables X and Y 29
27. Scatter diagrams illustrating different correlations 30
28. Effect of upward aggregation on rates computed for minor civil divisions and counties of a hypothetical state 31
29. An extreme effect of upward aggregation on cartographic correlation and scatter diagrams 31
30. Maximized and minimized visual correlations with a referent variable 32
31. Portraying the association among three variables with a complex multiple-variable map 33
32. A simple single-theme map illustrating one aspect of the association among three variables 33
33. Format of a leaf in a Triptik prepared by the American Automobile Association 36
34. Intersection of Interstates 81 and 690 in Syracuse, New York 37
35. Example of a paper street 38
36. A schematic bus-route map 39
37. Census subdivisions of an urbanized area 39
38. A census block as a linear graph and an assemblage of 0-cells, 1-cells, and 2-cells 40
39. Representation of a DIME record 41
40. John Snow's map of cholera deaths in the vicinity of London's Broad Street Pump 41
41. Sternglass's maps of the association between excess infant mortality and a New Mexico atomic test site 42
42. Bunge's map of the islands and continents of the world's children 43
43. Map from Continental Airlines' advertisement "We've got connections" 43
44. Eastern portion of Steinway piano map 44
45. "The united state of Marine Midland" 44
46. Spheres of influence on a Nazi propaganda map 45

I. ELEMENTS OF A MAP

"What is a map?" is not a trivial question. The characteristics that distinguish maps from graphs, watercolors, and photographs are not evident in the common synonyms: plan, chart, and diagram. Plans need not show relative location, charts can be large graphs hung on a wall to illustrate economic trends, and diagrams are used, among other things, to assist befuddled parents in assembling toys. The three attributes all maps share are scale, projection, and symbolization; all advantages and limitations of maps derive from the degree to which maps reduce and generalize reality, compress or expand shapes and distances, and portray selected phenomena with signs that communicate, without necessarily resembling, visible or invisible characteristics of the landscape.

The three elements of a map are interdependent. Scale influences the amount of detail that can be shown and determines whether or not a particular kind of symbol will be visually effective. Scale also varies from place to place, and the degree of this variation depends upon the projection employed. The graphic expression of the projection, in turn, is controlled by symbols used to represent coastlines, meridians and parallels, political boundaries, and other features that provide the user with a locational frame of reference. Despite this interdependence, however, a map maker has considerable freedom in choosing a projection, a scale, and a set of symbols. Each element requires a separate decision; each decision, if not properly made, might render the map less useful. Before proceeding further, these three elements should be discussed in greater detail.

Projection

Maps should be convenient to use. Part of their convenience lies in the ease with which they can be carried about and stored. Hundreds of maps can be bound together in an atlas occupying a fraction of a cubic meter. Flat maps can be rolled or folded; if any object cannot easily be stored until needed, its usefulness is reduced substantially. Yet, projections, which transform curved surfaces, such as those of the Earth, the Moon, or Mars, into planes, cannot yield flat maps without distorting shapes and distance relationships. Without map projections, however, all maps (except large-scale maps of small regions, where spherical curvature is negligible) would be globes or portions of globes—bulky, expensive, and difficult to mass-produce and to store. In order to scan a worldwide distribution, moreover, the users would need to rotate and possibly tilt the globe as well as move their eyes. Despite their inherent geometric distortions, the advantages of flat maps far outweigh their disadvantages, whereas the advantages associated with using large, distortion-free globes are outweighed for most purposes by the sheer difficulty of handling.

The distortions present in flat maps can be understood by considering map projection as a two-stage process. Only scale is changed in the first stage, in which a curved surface is reduced to a globe with a radius appropriate to the desired flat map. Geometric relationships are as yet unchanged; the distances among any three points on the globe retain the same ratio to the distances among the corresponding points on the original curved surface and their positions relative to one another remain the same.

In the second stage, an easily flattened surface is placed in contact with the globe, and all points on the globe are assigned new locations on this *developable surface*. The three most common developable surfaces are the plane, the cylinder, and the cone (Figure 1). The plane becomes a flat map directly, whereas the cylinder and cone must be slit before development (flattening).

Points and lines on the globe might be projected onto the developable surface by light rays emitted from the globe's center or from any other source. This optical projection method is not the only means of effecting transformations from spherical coordinates (latitude and longitude) on the globe to plane coordinates (the X and Y of a standard rectangular coordinate system) on the flat map; mathematical formulas can represent all standard projections, even those that cannot be constructed from a light source. For example, a variety of different spacings can separate the parallels projected as concentric circles onto a plane touching a globe at the North Pole, but very few of the many possible *azimuthal* projections (i.e., projections onto a plane) can be drawn without either consulting a table or performing the calculations.

The distinctive global patterns of parallels (east-west circles) and meridians (north-south circles) projected onto planes, cylinders, and cones are the *graticules* (grids) of the resulting azimuthal, cylindrical, and conic projections (Figure 2). Examination of these projected grids indicates that most distance relationships have been destroyed by the projection. On the azimuthal projection the central point represents the North Pole, and the heavier lines represent the Equator and the South Pole. Note that the South Pole, a point on the globe, has

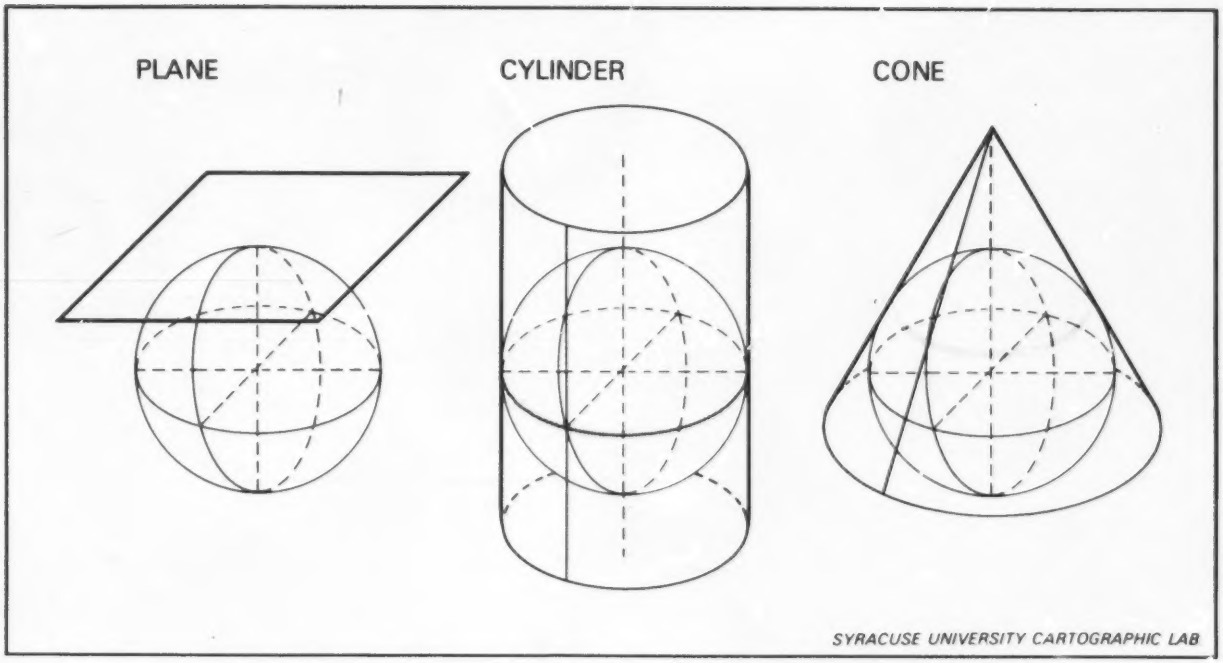

Figure 1. Profiles of developable surfaces and the globe.

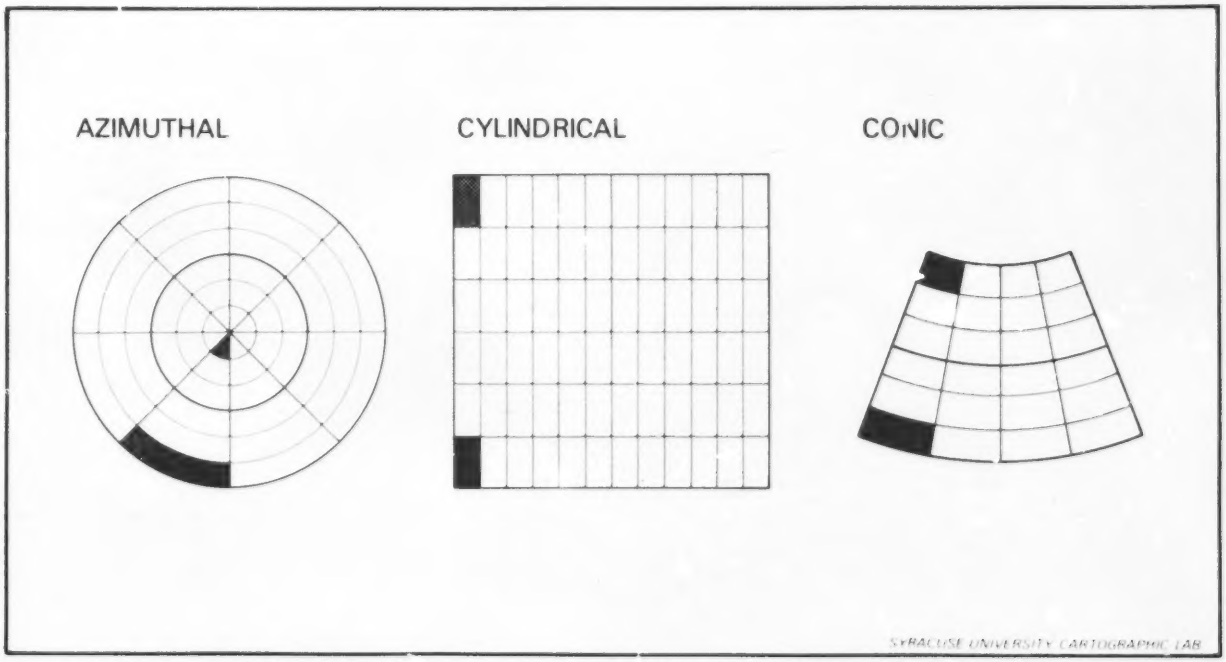

Figure 2. Graticules of azimuthal, cylindrical, and conic projections. The shaded zones have the same area and shape in both the northern and southern hemispheres. Note that the azimuthal and conic projections used here greatly distort area as does this cylindrical projection on which areal distortion is symmetric about the Equator. No projection preserves the true shapes of these regions' outside boundaries; each developable surface yields a distorted shape peculiar to the projection's graticule.

been stretched to a circle with a finite diameter. Its scale—the ratio of length on the map to length on the Earth—is now infinitely large. The conic projection, where the poles are represented by circular arcs of finite length, and the cylindrical projection, where both poles are portrayed as straight lines as long as the Equator, also indicate distortion.

Other distances are also distorted. On the azimuthal graticule, where, in this case, parallels are evenly spaced, true distance relationships are maintained only along meridians; in the east-west direction, for instance, scale becomes progressively larger with increasing distance from the center of the projection. The cylindrical projection, drawn here to represent the entire globe, has true scale only along the Equator. Along the meridians, which are twice the length of the Equator in this example, the scale is twice that of the globe. Because the parallels are equally spaced, this north-south scale is constant; however, the progressive stretching of parallels poleward from the Equator produces an enlargement of east-west distance with increasing latitude.

On the conic projection shown in Figure 2, east-west scale is greater than the true scale (of the globe) along all parallels except the single *standard parallel* at which the cone touches the globe. The cylindrical projection shown here also has a standard parallel; scale is not distorted at the Equator where the cylinder is in contact with the globe. In general, distortion of scale—and, as a result, of distance—increases as the distance from a line of contact between the generating globe and the developable surface becomes greater.

Stretching that distorts distance relationships will also distort shape and direction. For example, on the cylindrical projection in Figure 2, in only the cardinal directions (north, south, east, and west) do all places in the same geographic direction away from a point lie along the same straight line away from that point. Moreover, because the projection distorts all angles, except for the 90° angles between meridians and parallels, the shapes of continents, rivers, and other features that might be plotted on this graticule would also be distorted. In fact, *all* map projections distort the shapes of areal features, large or small! Although projections with the property of *conformality* preserve angular relationships within hypothetical, infinitely small areas around points, gross shape is always distorted since no projection preserves distance relationships among all points on a flat map.

Area is another geometric property distorted on map projections. This can be observed on the conic graticule in Figure 2, where the upper and lower arcs represent the North and South Poles. Here the two shaded cells represent equivalent areas on the globe, although the cell at the North Pole is substantially smaller on the projection than the corresponding cell at the South Pole. Relative areal distortion is also evident on the azimuthal projection, where equivalent areas (shaded) near opposite poles are greatly disparate. On the cylindrical projection, the poleward cells, although their areas are not distorted relative to each other, occupy the same area on the map as cells touching the Equator. Since meridians converge to polar points on the globe, instead of running parallel to each other, in this example polar areas are substantially enlarged.

Map projections can, however, preserve true area relationships. On all three types of projection the circles, straight lines, or arcs representing parallels can be repositioned so that the area bounded by any two neighboring parallels is in correct proportion to the area between any other pair of parallels on the map. Thus, adjacent parallels on the cylindrical projection would be spaced closer near the poles than at the Equator. The ability of these *equivalent* or *equal-area* projections to portray accurately the relative areas of continents, countries, and other regions is important, because the map reader will be less likely to misjudge, for example, the relative sizes of Greenland and South America. Moreover, if a map were symbolized with dots, each representing the same number of persons, cattle, or acres of wheat, the use of an equivalent projection would not promote incorrect estimates of density. For example, if two territories occupy 1,000 square kilometers on the Earth, and if they both have 100,000 uniformly dispersed inhabitants to be symbolized by 100 dots, a map projection that greatly distorts area might misrepresent the region with the smaller projected area as having a substantially greater population density.

Every map projection is a compromise. An ideal projection might be both conformal and equivalent, but such a projection is impossible because conformality and equivalence are mutually exclusive. For some applications an appropriate projection might preserve area while distorting angles as little as possible; this is common on distribution maps where the map reader is expected to compare areas and also identify geographic features. In other cases both areal and angular distortions might be tolerated if neither type of distortion is great enough to interfere with the utility of the map; U.S. Geological Survey topographic maps, for instance, use a polyconic projection, which distorts both area and angles, yet permits generally accurate distance measurements for small areas. For individual continents and smaller portions of the earth an acceptable combination of the distortions of area, angles, distance, and direction can often be obtained by carefully selecting a developable surface that lies close to the area of interest. The many possibilities available to the map author are discussed in elementary textbooks on cartography (Robinson and Sale, 1969: 199-248) and in more advanced works devoted solely to projections (Maling, 1973; Richardus and Adler, 1972). Both map maker and map user should understand not only the necessary evils resulting from projections but the numerous benefits as well.

Scale and Generalization

Scale is the ratio of distance on the map to the corresponding distance on the ground. It can be shown on a map 1) as the familiar bar scale. 2) verbally as, for instance, "one inch represents one mile," or 3) as a ratio or fraction. By convention, the numerator of the ratio is always one, and the numbers refer to no particular units. The ratio scale 1:24,000, found on many topographic maps produced by the U.S. Geological Survey, has no dimensions and can be interpreted as "one inch on the map represents 24,000 inches on the ground," "one foot equals 24,000 feet," or "one centimeter represents 24,000 centimeters." So long as both the numerator and the denominator of the ratio represent the same unit (e.g., inches, feet, or centimeters), the scale is valid. If different units of measurement are to be used, an appropriate conversion must be made. Thus, since 24,000 inches is also 2,000 feet, this scale can be expressed as "one inch represents 2,000 feet."

When the denominator is relatively small, say 10,000, the resulting fraction (1/10,000) is comparatively large, and the map is said to have a larger scale than, for example, another map at 1:250,000. Since large-scale maps represent less land on a given size sheet of paper than do small-scale maps, large-scale maps can present more detail.

Distance measurements can be made along any line on a 1:24,000 map and converted to ground distance. A two-inch line represents 2,000 feet regardless of its direction. Distortion of distance resulting from the projection is minimal; inaccuracy is more likely to result from the map user's error in measuring the length of the line or from the map maker's error in placing symbols on the map. This latter difficulty in positioning symbols is recognized by federal agencies, which have adopted the National Map Accuracy Standards. Points on a completed map are sampled and rechecked for correct positioning. For a map to meet these standards, no more than ten percent of the points may be more than 0.85 mm (1/30 inch) away from their true position if the scale is larger than 1:20,000. On smaller-scale maps the accuracy demanded is 0.5 mm (1/50 inch). Other criteria are employed for elevations on topographic and hydrographic maps, and the U.S. Geological Survey, after studying the statistical distribution of map errors, developed its own criteria, which are more complicated as well as more realistic (Doyle *et al.*, 1975: 1077-1078). Their method and the National Map Accuracy Standards both recognize, however, that on less detailed, smaller-scale maps the symbols representing characteristics of the physical and social landscapes commonly occupy more space on the map than if they were drawn at true scale. On a 1:250,000 map, for instance, a line representing a country road might be 0.5 mm wide in order to be visible. If the line's width were consistent with the map's scale, the actual width of the road would be 125 mm (410 feet, the height of a thirty-story building)! This greatly enlarged symbol simplifies the map maker's task of correctly positioning an ordinary state, county, or town road, which, given the accuracy threshold of another 0.5 mm, might be located the equivalent of 800 feet from its true alignment and still be acceptably represented!

Maps at scales of 1:250,000 and smaller are not, however, intended to permit accurate measurement of the widths of roads, railways, or streams. Their purpose is to show, with reasonable accuracy, the relative *positions* of these and other features. Many phenomena, such as political boundaries and contour lines, have no real width but must be drawn as though they were broad bands across the Earth. The goals of accurate positioning and effective communication are in greater conflict where, say, a narrow gap in a ridge contains a stream flanked on both sides by roads and railways. If the slopes of the gap are steep and must be represented by closely spaced contours, these might be permitted to merge, but a blue band symbolizing the drainage channel, the red lines showing the highways, and the black lines representing the railroads cannot be superimposed on the map without causing an ugly, incomprehensible blob of ink. One solution is to maintain normal accuracy for the drainage but to offset the transportation routes and the contours as much as necessary to prevent excessive crowding. Accuracy of one sort is sacrificed, but the accuracy of the relative position of the features is preserved.

Lines on a map must often be smoothed for the sake of clarity. Where the terrain is rugged, highways depicted on a one-page map in a road atlas cannot exhibit all the curves of their actual alignments. Meandering rivers must, in a sense, be shortened on small-scale maps. The crenulations of coastlines must also be smoothed, although it might be desirable to include a few indentations, suitably enlarged for clarity, to indicate that the shoreline is not as simple as it might appear. Smoothing or filtering of detail is mandatory if a map is to be more than a collage of incomprehensible symbols.

This process of *generalization* involves the selection of both meaningful details and relevant features. The smaller the scale of the map, the fewer the number and types of features that can be portrayed. A comparison of the road networks represented on maps at two different scales illustrates this point. The left-hand map in Figure 3 has been copied directly from a 1:24,000 planimetric quadrangle sheet. To its right the highways, drainage, and rail line have been photographically enlarged to the same scale from a 1:250,000 map prepared for regional transportation planning. (Color printing on the original permitted ready differentiation among the symbols for streams, railroads, different categories of highway, and political boundaries.) On this more generalized 1:250,000 map no houses are shown, and minor roads and smaller streams have been excluded. Symbols for those features retained

Figure 3. Example of loss of detail as a map's scale is reduced Sources: New York State Department of Transportation, 1:24,000 Jamesville Quadrangle, 1973 (left) and 1:250,000 New York State Map, 1974, central section (right); copied with permission.

at this smaller scale occupy more earth space than the same symbols at a scale of 1:24,000. Effective generalization also requires a substantial smoothing of the shoreline of Jamesville Reservoir, including the omission of the island near the west shore, and the elimination of detail along roads, stream channels, and the railway, which has been relocated some distance from the adjacent highway. The straight-line town boundaries, however, required no alteration of detail, but the shields for County Routes 1 and 144 are not present on the more generalized map. In fact, to prevent overcrowding, only state, federal, and interstate highways are labeled at the smaller scale.

The degree of generalization needed for clarity depends on scale, the complexity of the phenomena portrayed, and the theme or purpose of the map. To avoid clutter and confusion, only necessary features and relevant details should be included. The large-scale topographic map, for example, is not a good street guide, since only principal roads are labeled, whereas a map intended for locating intersections need not be concerned with elevation, tree cover, or individual residences. Houses and other buildings are useful reference points in open country, where they can be indicated as separate structures on topographic maps; the clustering of dwellings and commercial buildings in cities and towns, however, mandates the use of a tint screen (ususally a light red) for built-up areas where only schools, churches, and other landmark buildings are shown.

Even when a map's intended use is more narrowly defined, phenomena related to the theme seldom have a uniform spatial distribution. Thus, a single standard for feature selection might not be appropriate for all parts of a map. As an example, Baltimore, one of the 15 largest metropolitan areas in the United States, is often not labeled on page-size maps of the U.S. because it is near Washington, D.C. The same map might include Boise, Idaho, which has but a fraction of Baltimore's population but is located in an area with few large cities. Obviously, neither population size nor national prominence supports this decision, made in an attempt to balance the needs of visual appearance and information content. Responding to these conflicting demands is a major intellectual challenge of map making.

Symbolization

Representing a city with a small circle is a generalization, since few urban areas have circular boundaries; when many cities are represented by the same type of circle, the process is called symbolization. After a feature has been selected and its geometry simplified, in this case by reducing it to a point, a graphic symbol must be used to present the feature to the reader.

Mapping convention, neatness, and the ease with which an entire symbol or its individual elements

can be replicated are primary criteria in the selection of map symbols. In addition to pen and ink, straight edge, and French curve, aids used in symbolizing maps include templates (for circles, highway shields, and other geometrically simple designs), sheets of preprinted dry transfer or wax-backed point and area symbols, and thin rolls of tape with solid, parallel, dotted, and dashed lines. Although semi-automated mapping with the digital computer, line plotter, and COM (Computer-Output-Microfilm) unit and advanced production methods, such as negative scribing and photographic screening, have changed markedly the operations of some large mapping agencies and firms, these more modern technologies have not substantially altered existing traditions of map symbolization.

Convention holds that certain types of symbols are appropriate for certain types of phenomena. Linear symbols, for example, solid, dashed, dotted, and double lines (Figure 4), are used for linear features, such as boundaries and transportation routes. Contours and the lines of block diagrams (used to portray three-dimensional distributions) are also considered linear symbols. Yet, when lines or dots are grouped to form a coherent areal pattern, the resulting symbols are employed largely for showing quantitative or qualitative differences for two-dimensional areal units. Another type of area symbol is color shading. Dots, however, are used as individual symbols 1) on dot maps that emphasize geographic variations in density and 2) for point phenomena, such as cities or factory sites for which the actual boundaries have been generalized to a point. In the former case, one dot usually represents many objects (such as 200 dairy cattle or 500 grape vines), whereas in the latter instance a separate dot symbolizes each entity. Qualitative differences among point features might be represented by pictorial symbols (such as miniature drawings of factories or churches) or by various geometric designs (including squares, triangles, and stars). Spatial variations of magnitude can be drawn so that the circles' areas have a constant ratio to the mapped values (such as population or numbers of blue-collar employees) they represent. These examples illustrate, but do not exhaust, the customary practices used in choosing map symbols. Although blind adherence can only stifle mapping, the map maker must remember that experienced map readers tend to associate specific types of symbols with certain map themes (Dobson, 1975). Radical departures from these customs, therefore, might impede map reading (Jenks, 1976:14).

Since the variety of numerical values or landscape features depicted on a map commonly exceeds the number of different symbols employed, symbolization usually requires classification. Categorizations can be qualitative when, for example,

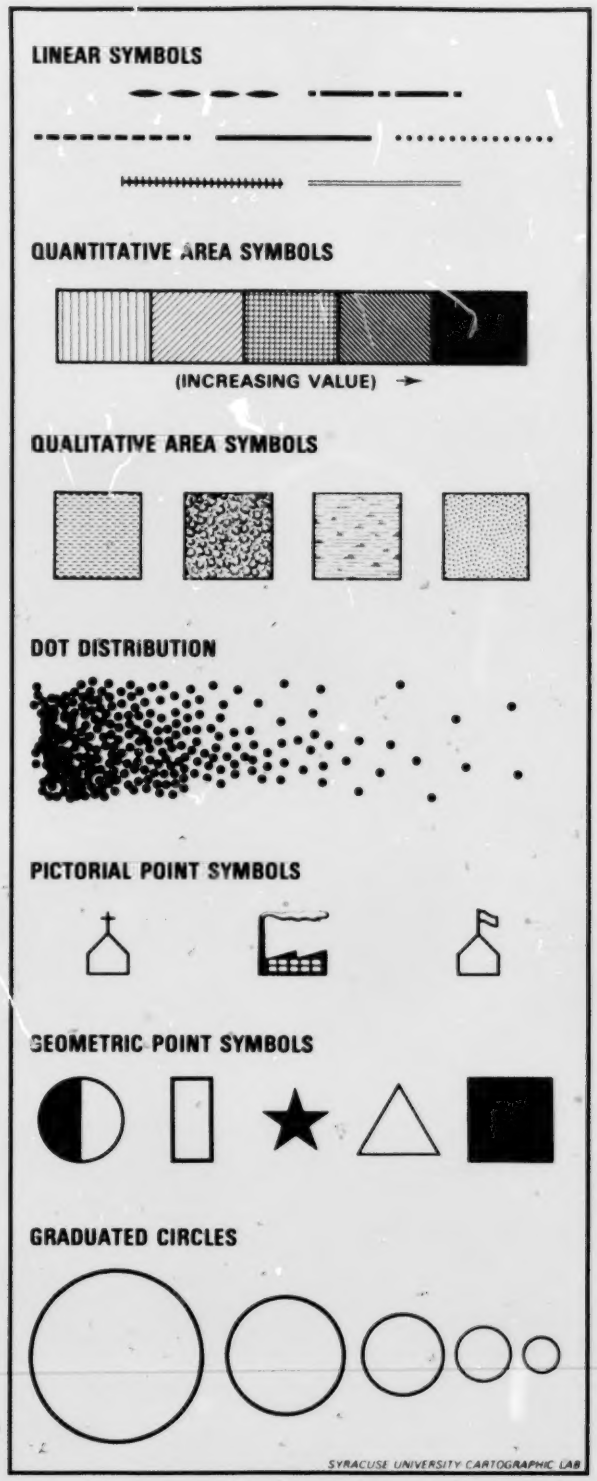

Figure 4. Examples of map symbols.

areas are given labels such as "commercial" or "industrial," or quantitative, in the case of fifty states grouped into five classes according to median family incomes. In this latter instance, the map user must not picture a state as a homogeneous unit without differences between urban and rural areas and between wealthy suburbs and impoverished ghettos. Nor, in the former instance, should all commercial areas be considered devoid of residences. In both cases, a map maker might elect to show more geographic detail or to employ a more intricate classification, but a map's objective is more easily accomplished if excessive detail and elaborate legends are avoided. Maps, like books, can be informative without being exhaustive.

Symbolization, projection, and generalization all distort reality. They need not, however, distort the truth. When a parent asks, "Where have you been?" the child replying with an account of every minute of the afternoon might well becloud eating five candy bars with "...and then I had something to eat at the Jacksons'." This type of evasion, of course, is deliberate, but even if the child had not spoiled his appetite, the statement, "I was playing with Betty and Jake," is direct, fully adequate, and preferred. Both the child and the map maker must decide how much their audience can be told without becoming bored, confused, or exasperated. If "to distort" is "to lie," then maps must lie. Their lies, however, are usually white lies, not deliberate fabrications. Making a road relatively wider than it is on the Earth makes it visible; distorting distances on a projection enables the map user to see the whole Earth at once; separating features by greater than Earth distances allows representation of relative positions. Distortion is necessary in order that the map reader be permitted to comprehend the meaning of the map.

II. CARTOGRAPHIC COMMUNICATION

Mapping, the process of designing, compiling, and producing maps, can be distinguished from cartography, the study of mapping methods and map communication. This differentiation between the technology and the art and science of maps does not imply an inherent separation of roles—map makers with decision-making responsibilities are cartographers, even though cartographers need never actually draw a map. It does, however, indicate that knowledge about map production and use demands more than the mechanical artistic skills required to draw an orderly representation of the landscape.

Major Factors of Map Communication

The central theme of cartography is the cartographic communication process. Here the actual map is but one concern in a chain starting with the image someone wants to convey and culminating in the intellectual or physical responses of the map user. The major factors in this linkage are 1) the map author; 2) the intended message of the map; 3) the mapping technique; 4) the map reader; and 5) the message received by the map reader. The first four of these components affect, in a different way, the efficacy of cartographic communication as reflected by the fifth factor.

Map authors might be writers, advertisers, editors of atlases, students, educators, government officials, entrepreneurs of geographic information, or anyone trying to communicate geographic information. They need not be cartographers, nor do they always employ the services of a cartographer. As initiators of cartographic communication they should know not only what they want their maps to show but also the limits of mapping technologies and the needs and map-reading abilities of their audiences. A map author's deficiencies in any of these areas might lead to the map user's incorrect interpretation of the map or, as might be more common than cartographers realize, a map that is largely ignored. A frequent example of an unused map is the textbook illustration that solicits little more than a passing glance from the student who views maps as fewer pages to read.

The message intended by the map may be simple or complex, but this message must be clear in the mind of the map author; otherwise, the map is likely to be deficient. Some of the least effective maps are those included in professional articles, textbooks, and official reports solely as window dressing because other authors of similar material also employ maps. Moreover, even if a map is appropriate, the map author's failure to identify precisely what the map is to say often leads to the inclusion of extraneous details that can only obscure the message. Similarly, if the message is really two or more separate messages, each of which would be better served by an individual map, the resulting single map might unduly tax the reader's ability to unscramble its various meanings.

Mapping technique is important for obvious reasons: some projections, methods of symbolization, and degrees of generalization are more appropriate than others in facilitating cartographic communication. Morrison (1971:1-8), in a study of different procedures for interpolating isolines (lines connecting points of equal value) from scattered data points, notes that there are several possible sources of error: 1) in the collection, recording, and manipulation of data; 2) in design, drafting, and reproduction; and 3) in map reading and map analysis. The method-produced errors can occur at any stage between the collection and adjustment of source data and the placing of the first mark on the final drawing. On isoline maps, for example, inaccuracies might result from the selection of sample size, sample type, and the interpolation model used to estimate surface values where not provided in the original data (Morrison, 1971:12-13). Because some mapping methods are more complex and error-prone than others, the selection of a particular procedure for generalization, classification, and symbolization is another factor in method-produced error. The decision to prepare a dot map, which involves the placement of many dots on the final drawing, increases the likelihood of method-produced error. Furthermore, design errors associated with inappropriate symbolization might combine with a poor choice of projection or an unpleasing layout for the map, legend, and labels to thwart the transmission of the intended message.

Another possible obstacle to effective cartographic communication arises from the difficulty of the human nervous system to perceive correctly the relative sizes of graduated circles and the degrees of blackness of different shaded area symbols. Cartographers need to know more about the function of visual perception and its relation to map design (McCleary, 1970). Psychophysical experiments attempting to describe mathematically the relationships between symbols as stimuli on paper and the responses these symbols produce in the brain have led to methods for rescaling the sizes of graduated circles so that estimates of their magnitudes by map

readers better approximate the numerical values these symbols represent (Flannery, 1971). Other experiments by cartographers have resulted in methods for selecting more visually distinct gray-tone shading patterns for choroplethic maps* (Williams, 1958, Kimerling, 1975) and for adjusting the density of dots on dot maps to achieve improved estimates of relative concentration (Olson, 1977).

Yet, rescaling symbols to adjust for errors in visual estimation is only part of the solution. Training in map reading provides another answer. Olson (1975b), for instance, gave her subjects the opportunity to see some correct answers to tests judging the density of dots and the magnitude of graduated circles. Tests were administered before and after these training sessions, and the feedback produced appreciable improvement in the subjects' estimates. The need for adequate education in map reading tasks, however is much broader. Muehrcke (1974) calls for an increased understanding of the limitations of maps in order that decisions adverse to human needs and environmental quality not result from the misapplication of maps by either map maker or map reader. Balchin presents an argument for more thorough education in map reading and places *graphicacy*, "the educated counterpart of the visual-spatial aspect of human intelligence and communication," on an equal footing with verbal literacy, social articulateness, and numerical ability (1976:34). Blaut and Stea (1974) recognize the ability of three-year-olds to make and use maps and urge that formal map training begin when a child starts school.

The ability and personality of the map reader is the least controllable aspect of cartographic communication. Yet, even though the user's enthusiasm and skill in map analysis cannot be increased easily by the map maker, the user's experience with reality and his or her mapping needs must at least be recognized. A map to be used by planners and other officials supposedly familiar with their city is likely to be less readily interpreted by the average citizen who, as an illustration, might want to know only where a new sewer line is to be extended, not its diameter and other engineering specifications. Similarly, an atlas prepared for school children is best judged by the users in terms of their increased understanding of the Earth than by the subjective impressions of educators, administrators, and parents. Unfortunately, too few surveys of user needs and of the actual meaning derived from maps have been conducted. Moreover, acclaim by other cartographers is no guarantee that a map is most suited to its intended audience.

*Choropleth maps portray patterns or distributions of various absolute or relative phenomena by incorporating these data within preexisting boundaries of areal units, such as minor civil divisions, counties, states, and countries, or blocks, census tracts, economic regions, planning regions, and neighborhoods. Their boundary patterns differ from other isoline map patterns such as isobars (equal barometric pressures) or isohyets (equal precipitation totals) because the data themselves are used to form the areal boundary independent of any preexisting boundary. For example lines portraying density of population in the U.S. can follow county boundaries as the limits of a particular density, or they can connect points of equal density to form population density boundaries. The former lines portray population density via choropleths, the latter show population density via isolines. (For examples of choropleth maps, see Figures 21, 22, 24, and 26.)

Information Theory

Since maps are intended to transmit information, a useful means of studying the cartographic communication process is found in information theory. The generalized communication system (Figure 5) originally diagrammed by Johnson and Klare (1961) and used in several recent essays on cartographic communication (Board, 1967:673; Jolliffe, 1974:176; Robinson and Petchenik, 1975:9) provides a convenient starting point. This set of linkages can be used to model any type of information flow system, such as radio, speech, newspapers, and maps. Its end points, labeled "source" and "destination," are the originator and the recipient of the messages, symbols, or other discrete signals flowing through the system. At its more advanced levels, information theory endeavors to express mathematically the amount of information transferred from one stage in the system to the next. For discussions of cartographic communication, however, information theory can be used to indicate the different places where errors can enter the system; efforts might then be made to optimize the use of maps.

As a message within a communication system proceeds from source to destination it takes different forms. The first change occurs when the message is converted to code, as in the case of an idea written as a series of letters and punctuation marks. Next, a transmitter produces a signal that is carried by a communication channel, such as electromagnetic radiation, nerve fibers, or wires, to a receiver. After the message is received, the resulting code must then be decoded before delivery to the destination.

The channel's carrying capacity might limit the amount or rate of information flow through the system. Ordinary telephone wires, for instance, are usually adequate for signals transmitted for voice communication but cannot handle the more frequent signals a digital computer might generate; in this instance the rate of transmission must be slowed down or the quality of the circuit upgraded. Moreover, a message might be made more difficult to receive and decode if noise, say, cross talk during a telephone conversation, enters the channel. In general, *noise* is an unwanted signal that can or cannot be decoded. Noise might be incoherent or meaningless, as when crackling occurs during a telephone conversation, but coherent or meaningful noise can also occur. Unwanted signals coherent with the desired signal are also called *distortion*, a

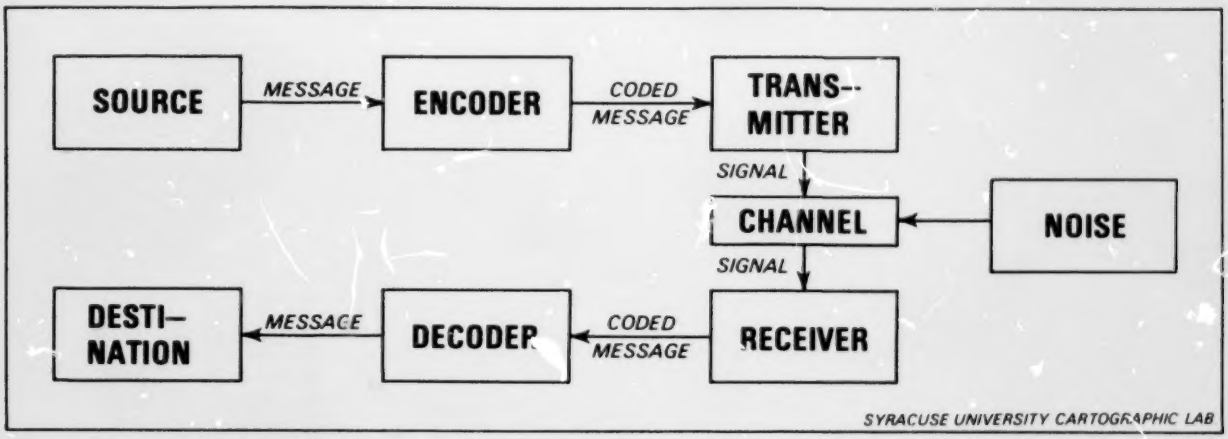

Figure 5. Model of a generalized communication system (after Johnson and Klare, 1961).

term that describes the poor sound quality of a cheap radio or the result of looking into a fun-house mirror at an amusement park. These are some of the more obvious types of distortion; all communication systems introduce distortion as they convey information (Young, 1971:7).

A device that rejects certain signals, such as radio waves not of a preferred frequency, while accepting others, is called a *filter*. Filters can screen out some noise or simplify more complex signals. They are not restricted only to receivers. A voice coder, for example, has an analyzer unit with a series of filters that decompose speech signals into different frequency bands before transmission through a channel to a synthesizer that remakes these signals into speech (Pierce, 1961:136-137). The resulting sounds often resemble a caricature of the original speech but are recognizable nonetheless. Thus, with the addition of filters, even our model of a generalized communication system can be more complex than that discussed above. Other worthwhile modifications recognize that, since all messages, transmitted, coded, or received, are signals flowing through channels, noise or distortion can enter a communication system on either side of the primary channel.

A Model of Cartographic Communication

The flow diagram of a generalized communication system can be made meaningful to cartography only if the number of stages is increased and filters are added. Furthermore, except for mishandling in transit or by other users, noise enters the system not at the main communication channel—the map—but at interfaces between other, adjacent stages in the system. In addition, a model of map communication must recognize that some of the cartographic functionaries play a dual role within the context of information theory. For instance, the map author is both the source of the map's intent and the encoder of real data, whereas the cartographer, who might or might not be the same person as the map author, is both an encoder who chooses map symbols and a transmitter who positions them on paper or on drafting film. The map user is the receiver, the decoder, and the destination. The model presented here (Figure 6) is an amplification of a diagram developed by Jolliffe (1974).

Although the message originates in reality, the source of the map's intellectual content is the map author. The idea contained in the map depends, in part, on what the author knows about reality. Real noise describes extraneous (or erroneous) information that might be introduced at the linkage between the real world and the map author; this noise is fully or partly countered by a data filter whereby irrelevant details are ignored. This filtering might be done by the map author who views the real world selectively or by a data-collection agency, such as the Bureau of the Census or the Geological Survey, which publishes documents presenting a necessarily limited, and possibly biased, version of reality. Obviously, this part of the diagram could be far more elaborate, but any amplification of this stage is more appropriate to discussions of scientific method and research design than to cartography.

What the author tells the cartographer is filtered by what the author views as the intended meaning of the map. An author unclear about a map's meaning or purpose imparts undue *author noise* to the system. An author not fully aware of the limitations of maps might decide to use a map when some other form of communication would be more effective. When author and cartographer are not the same individual, problems might also arise from the transfer of inexact instructions. Moreover, the cartographer is handicapped if not aware of the final, reproduced size of the map, since map size is an important determinant of optimal generalization and symbolization. Finally, an author ignorant of the intellectual or sensory capabilities of the map reader might well request a map too visually com-

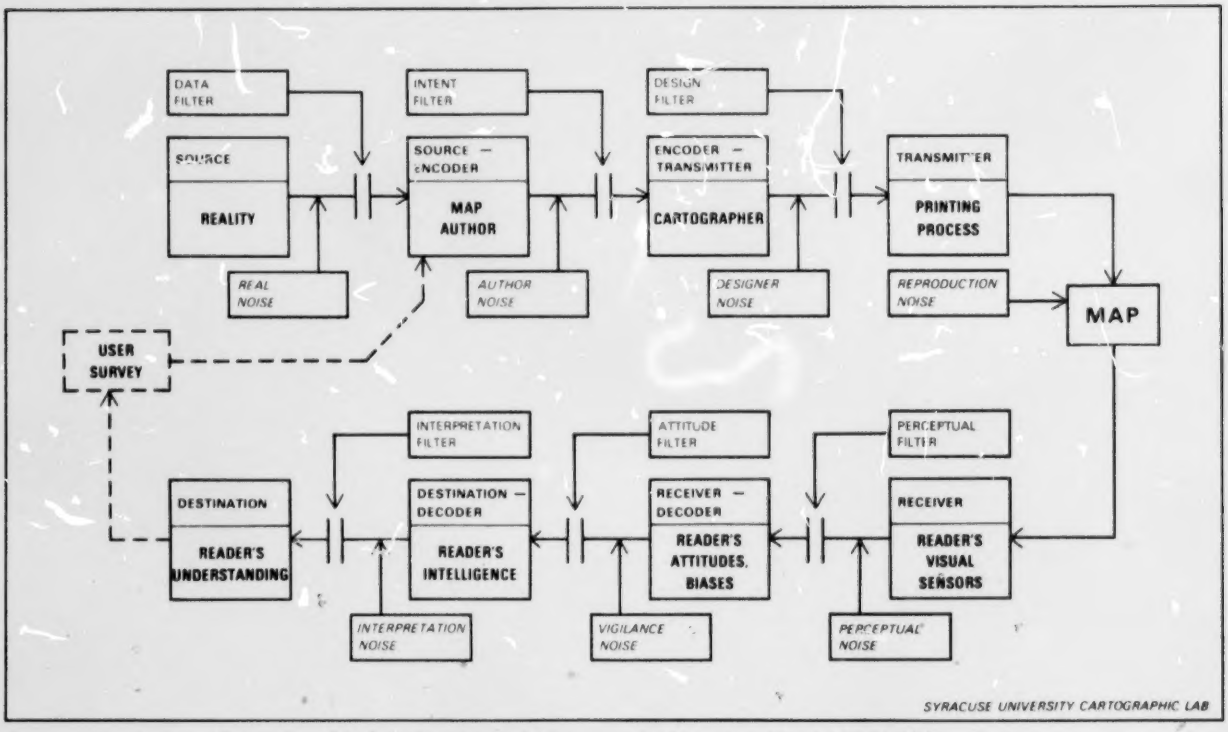

Figure 6. Model of cartographic communication (modified from Jolliffe, 1974).

plex to be understandable.

The cartographer can confuse the message by adding *designer noise*. Type might be too small to be read, symbols might not be readily differentiated by the reader, or the map might have a sloppy layout or clashing colors that tend to distract the reader. Similarly, a map that must hold the attention of a marginally interested reader might be too drab or commonplace. Other kinds of designer noise include the method-produced errors mentioned earlier in this chapter. A *design filter* can contribute to effective communication by removing unneeded detail that has somehow progressed this far in the flow from source to destination. Yet, although noise is almost universally undesirable, a filter can exert both positive and negative influences. Too much geographic detail might, for instance, be removed, leaving the reader with an inadequate locational framework. A map reader, after all, must be able to relate the symbols to his or her knowledge of reality.

At the printing stage *reproduction noise* can further distort the message. Color plates might be offset, thus yielding poor color registry—the overlap or underlap of different colors often noticeable in the Sunday comics. Sloppy printing also includes the loss of type during plate-making (when labels have been known to fall off a drawing) and the use of paper too porous to retain fine lines. A good cartographer will understand the limits of the printing process and will examine press proofs. The printing stage has no corresponding reproduction filter; the use of too little ink to produce a crisp image can be treated as another form of reproduction noise.

Differentiation of stages in cartographic communication is less obvious after the map has been printed. The primary receiver is the map reader's visual sensors, but attitudes toward both the map in question and maps in general will influence the thoroughness with which the reader scans the map. If the map is uninteresting or if the reader is indifferent to or repelled by maps, the map might be examined superficially or not at all. The reader's intelligence and knowledge will also affect map decoding ability, but the complex interrelationships of these concepts warrant their consideration as a single factor. Finally, the reader's possibly increased understanding of reality as a result of studying the map is another aspect of the message's destination. Separating these four stages in the diagram (Figure 6) is confounded by the continuous feedback occurring as the reader responds to one map symbol and then decides where else to look. For a more detailed discussion of map use and cartographic communication, see Robinson and Petchenik (1976).

Perception and cognition are both involved in map reading. Perception, whereby direct acquaintance with a stimulus is obtained through the sen-

ses, precedes cognition, in which the mind becomes sufficiently aware of objects or symbols to identify them and to initiate action as well. A person touching a hot stove, for instance, perceives heat as nerve endings in the fingers send messages to the brain; when cognition occurs, he or she rapidly withdraws the burned hand and shouts an appropriate expletive. When reading a map, the reader's visual sensors might perceive the relative magnitude of a graduated circle representing the value for San Francisco. Cognition occurs when the reader begins to look farther south to find the circle symbolizing California's other major city, Los Angeles. In cartographic communication these two processes are so intertwined that the term perception is applied, for convenience, to all acts of observing symbols and estimating their size, color, and shape. Cognition is thus reserved for acts of spatial recognition in which these symbols acquire meaning in terms of place or pattern.

Perceptual noise might deceive the map reader by altering, for example, the apparent relative size of a circle. Areas of larger circles are, in this case, visually underestimated relative to the areas of smaller circles. *Perceptual filters* act temporarily to screen out marks on a map when two or more stimuli, such as overlapping graduated circles, are in conflict. Another example of perceptual filtering is the *figure-ground* phenomenon whereby a significant symbol stands out from the surrounding ground detail with which it shares the field of view (Figure 7). Poor tonal contrast on a black-and-white map is but one design error that might confound the emergence of the figure from the ground (Dent, 1972b). On maps printed in color, differences in hue, brilliance, and tone generally facilitate figure-ground differentiation. Polychrome (color) maps, therefore, can contain a greater variety of symbols and more information than monochrome drawings. But even color maps can be too complex for ready perceptual filtering if their design is poor or if the author attempts to cram too many different types of information onto the same map. The effective capacity of the map as a communication channel is thus constrained by the limits of the reader's perceptual filter.

A map reader can be uncomfortable with maps in general, bored, distracted, or only marginally interested in what the map is attempting to show. In these cases *vigilance noise* enters the communication process and much useful information, including the whole meaning of the map, might be lost through inattention. In the extreme, the reader's *attitude filter* might lead to ignoring the map completely. Attitudes, which can be either positive or negative and which play important roles in all forms of behavior (Doob, 1947), are an important aspect of cartographic communication. Clearly, positive attitudes toward maps should increase the likelihood that the message intended by the map author will reach its destination. Negative attitudes, which deter communication, might be beyond the control of the map author; however, in some cases a map with an eye-catching design might overcome a negative attitude and catch the reader's attention. Dent (1975) addressed this problem, and Petchenik (1974) employed pairs of bipolar adjectives, such as "helpful...hindering," to determine readers' attitudes toward maps. Their approach might help cartographers identify map designs particularly ef-

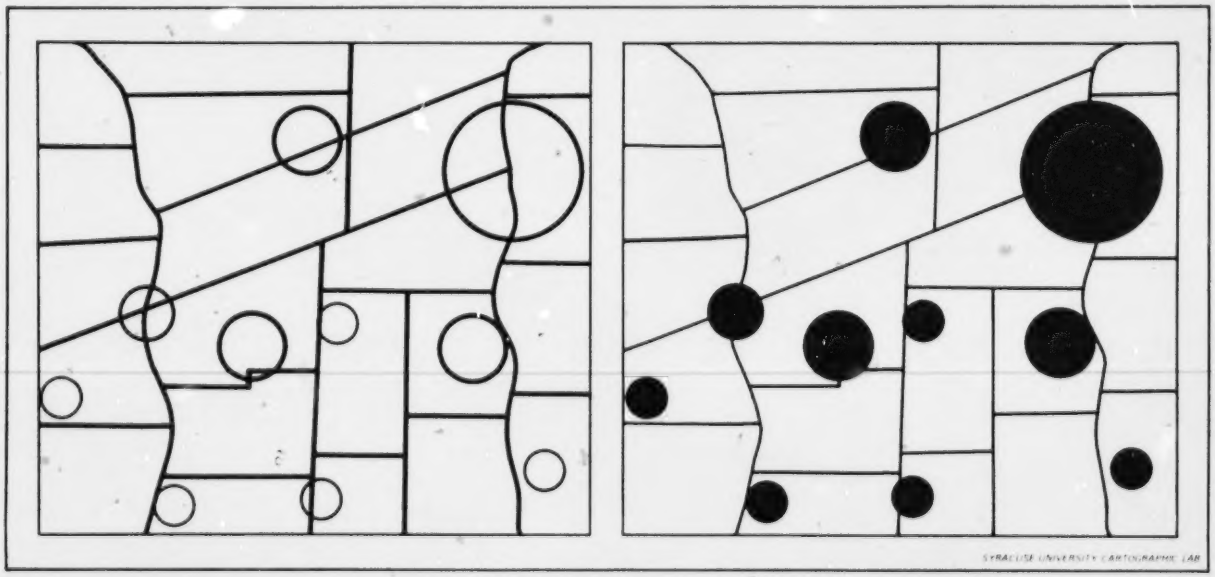

Figure 7. Poor (left) and good (right) figure-ground differentiation.

fective with otherwise uninterested readers.

Ignoring symbols not relevant to a particular map-reading task occurs at the destination-decoding stage. Here the *interpretation filter* permits the reader to overlook extraneous information and to assemble useful features into a meaningful interpretation of the map. Mistakes, however, are possible and probable, especially if the reader is ignorant of the map's subject matter or the region. Hence, *interpretation noise* can obscure the intended meaning. Moreover, since the mental processes involved at this stage are purely cognitive, the reader's increased understanding of reality might well exceed that intended by the map author (Robinson and Petchenik, 1975:11-12). Thus, any user survey, which provides a feedback loop for gauging the effectiveness of this communication system, must recognize that increased understanding or confusion following the reader's use of a map need not stem solely from the map itself.

This model of cartographic communication, although inadequate in its description of the mental operations accompanying map reading, might serve to highlight some strengths and weaknesses of maps as communication channels. Although the map author and cartographer have control over the map's content and graphic composition, they must be aware of perceptual limitations; otherwise, they might ask too much of the reader. They must eliminate undue complexity and attempt to heighten interest in their mapped message. All too often maps are sloppy, bland, or poorly integrated with the accompanying text. Can the reader be condemned for ignoring this type of map? Within limits, maps should be interesting as well as accurate.

Incorrect interpretations are the likely consequences of poor map-reading and analysis skills, and of a poor grasp of the geographical processes associated with the mapped phenomena. When these interpretations are translated into actions, the outcomes can be serious. Not only might drivers become lost, confused, and more likely to have accidents, but planning and military decisions based on erroneous map reading can have grave social, economic, political, and human costs. Is it any wonder then that the military places great emphasis on training in and research about map reading? Should not our general educational system do likewise? Because maps are indispensable for many tasks, educators at all levels should respond to this basic need. The public has a right to know when and how to use maps.

III. PROJECTIONS AND PRAGMATISM

Projections, one of the distortions required on a flat map representing the spatial relationships of a curved surface, can be an important source of designer noise in cartographic communication. Since distortion produced by common map projections is more apparent at the global or hemispherical level, projections are less likely to thwart effective cartographic communication at larger scales (showing small areas) for which suitable base maps are readily available from international, national, state, and local mapping agencies. The most effective map projection, however, is not always obtained by the thoughtful selection of an acceptable existing base map: a mapping task is often better served if the requirements are met by a projection designed, rather than chosen, for a particular need. Nevertheless, in practice, projections are all too often chosen for convenience; they might not hinder, but neither do they help the map.

Inappropriate choices of projections, now relatively rare occurrences, are most common among professionals in the communications industry not trained in cartography. Graphic artists, for instance, although highly skilled in design and production methods, usually know little more about maps than does the average person—the target of their advertisements, graphs, and pictorial layouts. Ironically, their cartographic work is often among the best in design and innovation, but they make errors stemming from nonexistent training in the principles of mapping.

Early in December 1975, for instance, President Gerald R. Ford visited the People's Republic of China. On the presidential flight between Washington and Peking, he stopped over in Alaska, at Fairbanks and Anchorage. These stops permitted the presidential party to view the trans-Alaska pipeline, and American news media gave this part of the trip front-page coverage. One television network mapped the route and the stop-over with continental outlines from an equatorially-centered cylindrical projection. This spatial perspective greatly distorted the purpose of the Alaskan stop, since Air Force One did not go out of its way to land in Alaska. A gnomonic projection, which portrays all great-circle routes* as straight lines, demonstrates clearly that Fairbanks is along the relatively direct route between Washington and Tokyo, where the plane was again refueled enroute to Peking (Figure 8).

This misuse of one type of map projection also illustrates how another projection could have been employed effectively and accurately. Although both projections distort the Earth's surface, the gnomonic map would not have distorted the significance of the Alaskan visit. Yet, its straight-line representation of great-circle routes limits the gnomonic projection to maps concerned with direct-route navigation. Distance, angles, areas, and shape are all subject to substantial distortion, particularly at the periphery of the map, in order that one aspect of the Earth's geometry—direct routes—be preserved.

There are many instances in which the effective use of a projection is quite limited. For some applications, moreover, the best projection has yet to be developed. This chapter, in exploring further the design filter associated with projections, discusses the construction of some easily drawn, one-of-a-kind projections that focus their distortion toward, not away from, the intended message of the map.

The Mercator Mystique

Networks of ribs of palm leaves were used to represent routes and wave patterns between the Marshall Islands; these crude stick charts were among the earliest maps. Later nautical maps of the thirteenth century also portrayed routes as straight lines; these portolan charts were ornate maps with compass roses oriented toward magnetic north (Thrower, 1972:38-42). Coastal features were emphasized along with compass bearings between ports. As larger parts of the Earth were mapped, navigators and cartographers became aware that lines of constant geographic direction, called *rhumb lines* or *loxodromes*, could not remain straight without a progressive increase in scale from the Equator poleward. Except for north-south or east-west orientations, rhumb lines on the globe are spiral routes that, in theory, would circle the Earth an infinite number of times and never reach the poles. When mapped as straight lines, rhumb lines require an increased poleward spacing of parallels. Yet, their representation is a boon to navigators who have only to maintain a constant course in going from one point to another.

An easily replicated solution to this problem did not appear until the latter part of the sixteenth century, when Gerhardus Mercator developed the projection that bears his name. Born in 1512 in Flanders, Mercator was a skilled engraver who

*A circle formed on the surface of a plane passed through the center of the earth. The shortest distance between two points on a sphere is the arc of the circumference of a great circle.

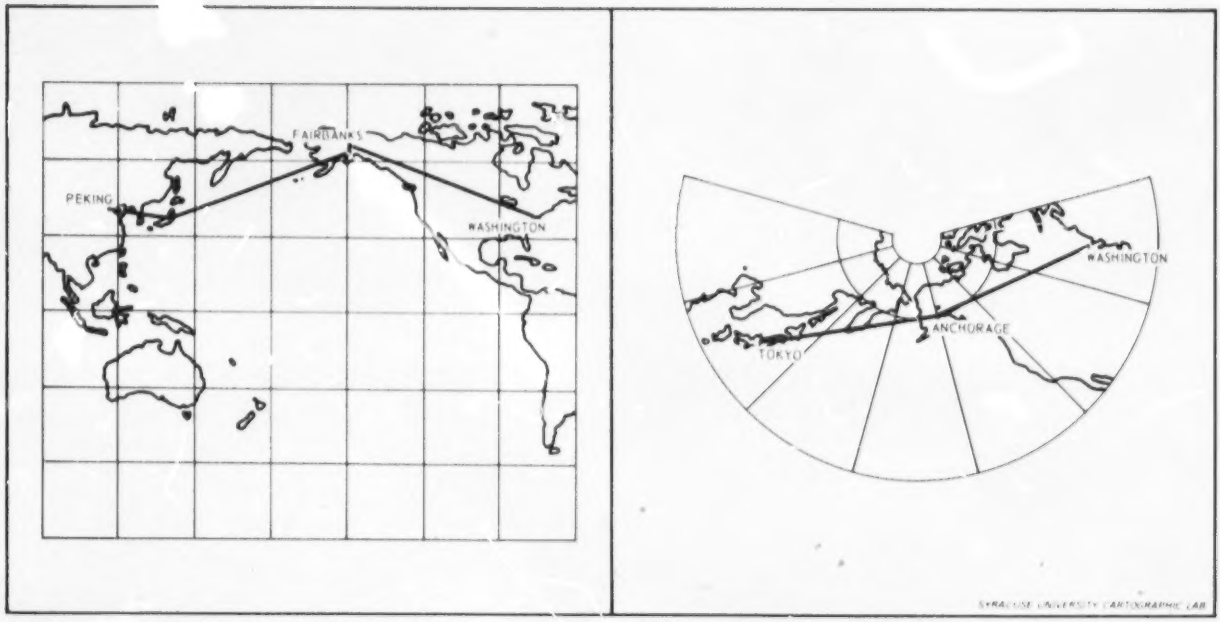

Figure 8. President Ford's flight from Washington to Peking, 1975. A standard cylindrical projection (left) portrays the Alaskan rest stop as a significant departure from a direct route, whereas a gnomonic projection (right) indicates that this stop represented little deviation from a great-circle route.

produced one of the early globes. As a land surveyor, he prepared maps of Europe and, in 1554, he was the first to use a conic projection with two standard parallels. His greatest achievement, however, was the design of a world map projection on which rhumb lines were straight lines intersecting the meridians at a constant angle. Thus with the aid of a protractor, the bearing (east or west of north) of a rhumb line between two ports can easily be estimated.

Rhumb lines, however, are not shortest-distance, great-circle routes. These direct routes generally appear as curves on a Mercator projection (Figure 9). Nonetheless a course can be divided into several shorter segments, each of which has a separate rhumb line that approximates more closely the great circle linking the terminal points of the longer route. This practice can shorten an otherwise lengthy voyage and also allow for intervening land masses.

The increasing poleward spacing between parallels was determined empirically by Mercator, although Edward Wright, an English mathematician, derived the formula underlying Mercator's graphic construction in 1590. Despite its current widespread use for marine and air navigation, the projection was not readily adopted by navigators of the sixteenth and seventeenth centuries (Thrower, 1972:55). Once its merits were recognized, however, the use of the Mercator projection—in a classic example of too-little-too-soon, too-much-too-late—was extended well beyond its intended nautical application. During the late 1930s, *Newsweek* still used the Mercator (Ristow, 1957:387), and this projection was also a convenient tool for Nazi geopoliticians and propagandists (Boggs, 1947:471). During the 1950s the Mercator's enlargement of northern areas made it a favorite of persons wanting to exaggerate the Communist threat (Figure 9). Even today, many outline maps used for geography units in elementary schools are based on the Mercator grid.

Between 1910 and 1920, J. Paul Goode experimented with interrupted map projections. At this time, the Mercator was still the most common projection for world maps in school atlases. Although it distorted area, the Mercator projection was at least familiar. A few equal-area projections had been used in classroom atlases before Goode, but none gained widespread acceptance, most likely because poleward features were compressed either as the spacing between adjacent parallels decreased or as other meridians were drawn inward toward the central meridian at the top and bottom points of the projection. Goode developed his homolosine (equal-area) projection by combining the homolographic (for areas poleward of 40° latitude) and the sinusoidal (for areas equatorward of 40° latitude) projections, each of which would give the best equal-area attributes for the areas to be mapped. Goode divided the Earth's land masses into twelve zones, each of which had its own locally centered projection (Figure 10). In this way he reduced the distortion of shape for each zone.

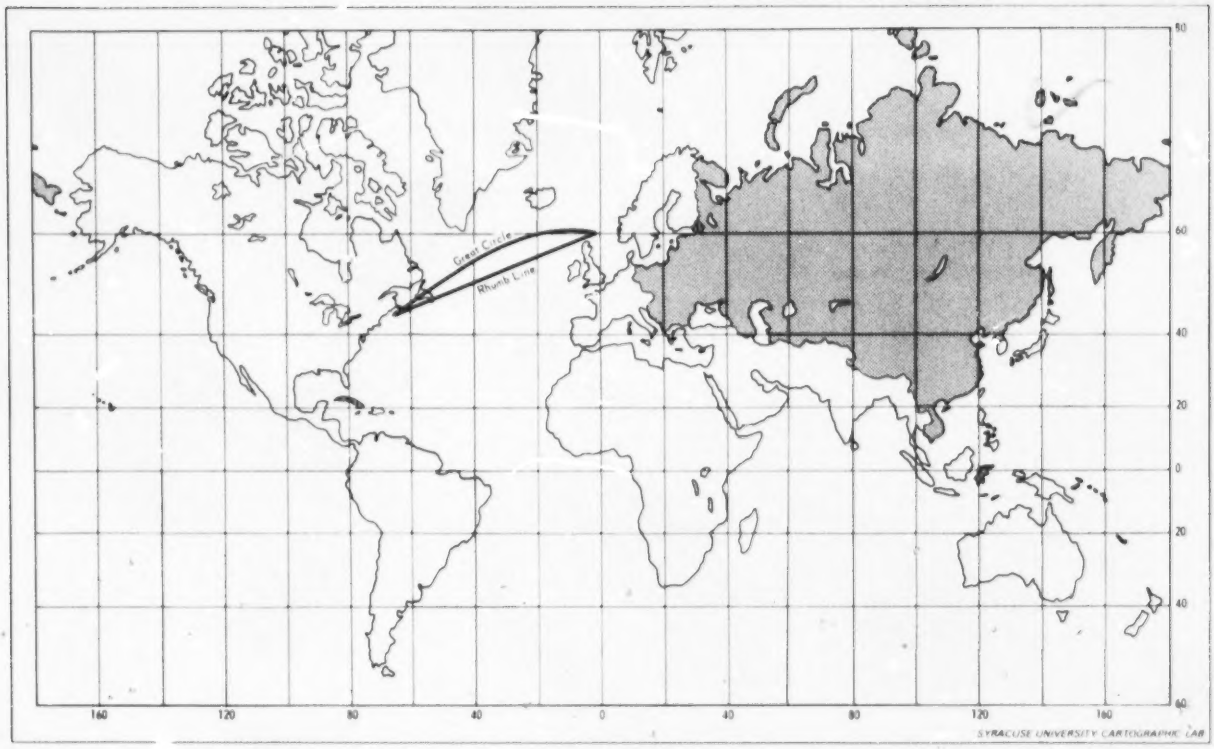

Figure 9. Distortion of distance and area on a Mercator projection. A shortest-distance, great-circle route appears as a lengthy arc, and poleward stretching amplifies the land area of the Communist world.

These twelve projections were then spliced together with parallels interrupted over water between North America and Eurasia, between South America and the islands of the South Pacific, between South America and Africa, and between Africa and Australia. Each lobe extending poleward from the Equator was divided into two separate zones at 40° north latitude and 40° south latitude (Figure 10). Goode's

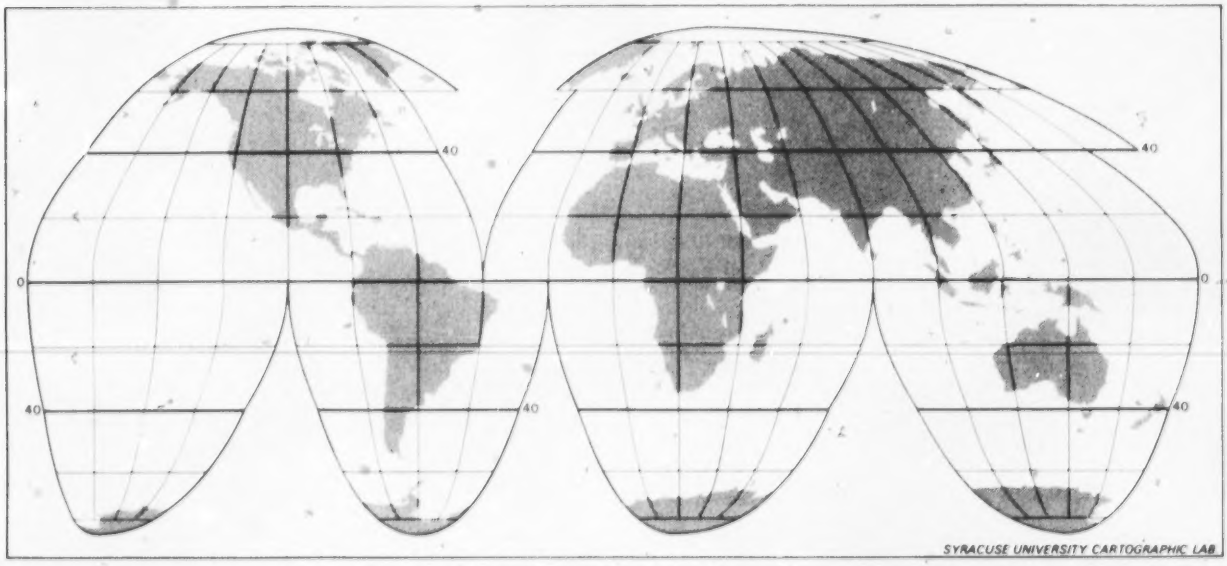

Figure 10. Goode's interrupted homolosine equal-area projection.

projection met his criteria for an equal-area map which attempted to preserve the essential shapes of continents (Goode, 1925:121). Since the 1930s, this and similar interrupted projections have replaced the Mercator as the standard projection for world maps of land features. Moreover, the variety of commonly used projections has increased, thereby providing atlas users with a desirable assortment of world views.

Area Cartograms

Presidents are often identified by their home state: John Kennedy was from Massachusetts, Lyndon Johnson from Texas, and Richard Nixon was born in California. Their opponents also have conspicuous regional ties: Barry Goldwater hailed from Arizona, Hubert Humphrey from Minnesota, George Wallace from Alabama, and George McGovern from South Dakota. Before demonstrating national appeal, a candidate must first gain local and regional prominence. Thus, it is not surprising that a candidate for the presidency will capture an electoral majority within one of the country's major regions—the industrial Northeast, the South, the Midwest, or the West.

A candidate's percentage of the popular vote can be mapped, but because of our Constitution, a simple majority in a state gives a candidate all of the state's electoral votes. As an extreme example, a map of McGovern's winnings in 1972—Massachusetts and the District of Columbia—shows nothing more than voids in Nixon's landslide. Even allowing for the electoral college and unit rule, however, the 1972 McGovern map would be misleading. Washington, D.C. and the Commonwealth of Massachusetts occupy insignificant portions of the national map—0.23 percent of the country's 3,615,000 square miles—even though they contained a much higher percentage—3.2 percent—of the 538 electoral ballots cast in that election. Because their population densities are relatively high, a newspaper or magazine using a base map with an equal-area projection would only further enhance the Republican candidate's overwhelming victory. However, electors, not square miles, elect Presidents!

Most map readers, of course, could not be misled by this example. Yet, based on the number of electors in 1972, a candidate need only carry the eleven most populous states—California, New York, Pennsylvania, Illinois, Texas, Ohio, Michigan, Florida, New Jersey, Massachusetts, and Indiana—to receive a clear majority in the electoral college. A reader viewing an equal-area base map with only these states colored in might not, however, see this as an obvious, albeit narrow, victory. A perceived absence of areal dominance might also be equated with the lack of numerical dominance and lead to misinterpretations of other quantitative maps.

Consider, for instance, the world's known reserves of fossil fuels. Slightly over half of the world's oil is in the Middle East. Even Africa's reserves exceed those of North and South America combined. The United States, however, is comparatively well supplied with coal. Its coal reserves, in fact, exceed the combined resources of Europe and the Middle East. Although the distributions of potential oil and coal production could be shown on a conventional equivalent projection with area symbols representing different statistical categories (in either absolute barrels or tons, or in barrels or tons per square kilometer), the resulting maps would probably not emphasize this nation's short supply of petroleum or its abundance of coal. Even pictorial symbols, such as derricks and hopper cars, proportional in number to national or regional supplies, would be only marginally more effective. On the map for oil, moreover, the Middle East might be cluttered with overlapping derricks.

This message can be conveyed with greater impact by redrawing the map so that a region's mapped area is made proportional to its energy reserves (Figure 11). The resulting *contiguous area cartogram* can be a highly effective map projection if the identities of the individual mapping units are not destroyed as area is distorted. Although not a conventional map projection, the cartogram is a transformation of space that shares basic mathematical properties with more traditional map projections (Tobler, 1963). The distortion of land area to achieve equal density so that, for instance, one square centimeter anywhere on the map represents the same amount of coal or oil, is its identifying and most valuable property. Erwin Raisz (1934), an early advocate of these projections, used cartograms to illustrate geographic difference in population, national wealth, value added by manufacturing, value of farm products sold, and other economic variables. Raisz recognized the cartogram's value to both education and business.

In addition to more direct uses in which areas are merely distorted and possibly identified by name, area cartograms can also serve as useful base maps for shaded area symbols. Since most western peoples are concentrated in and around cities, for example, area screens placed inside the outlines of relatively small urban enumeration districts are generally inconspicuous when compared to the area symbols representing more extensive rural regions. Since metropolitan populations differ in many respects from rural populations, the minimized visual impact of area symbols representing city units yields unrepresentative mapped patterns. When a cartogram based on population is the base map, however, the reader is presented area shading symbols with areas directly proportional to their significance. These demographic base maps can be developed for population subgroups as well as for total numbers of inhabitants (Forster, 1966). Thus, the death rates of blacks can be shown on a cartogram based upon the more germane black population. If the region mapped is marked by geographic differ-

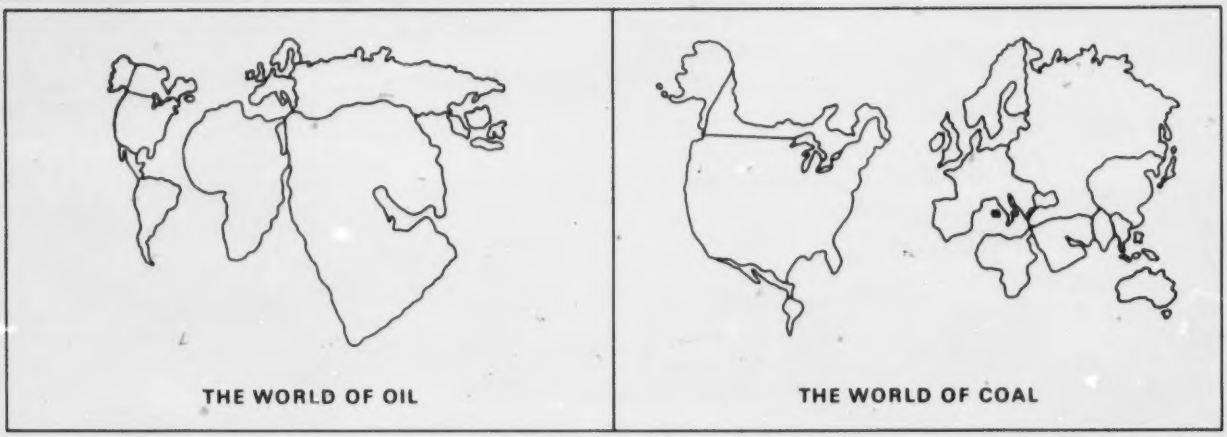

Figure 11. Contiguous area cartogram showing worldwide patterns of oil and coal reserves (courtesy Exxon Corporation).

ences in concentration between blacks and other racial groups, this type of map is less likely to result in misinterpretations than a conventional display that would, for example, overemphasize the spatial trends for relatively small numbers of rural blacks in the Northeast.

The construction of a contiguous area cartogram requires only a standard base map (Figure 12-A), a sheet of graph paper, a straight-edge, a pencil, and a good eraser. Begin by simplifying the boundaries (Figure 12-B). Since map readers generalize shape mentally, ten or fewer points that serve as cues for shape identification will usually be adequate (Dent, 1972a). Next, convert the numerical values for these areas into the number of grid squares that they will occupy on the graph paper. In this example the estimated 1975 populations of the six New England states are given in thousands (Figure 12-A). Dividing New Hampshire's value of 813 by a scaling constant of 25 yields 33 squares (813/25 33). This arbitrary constant was chosen so that, for this particular grid, the cartogram will be neither too small

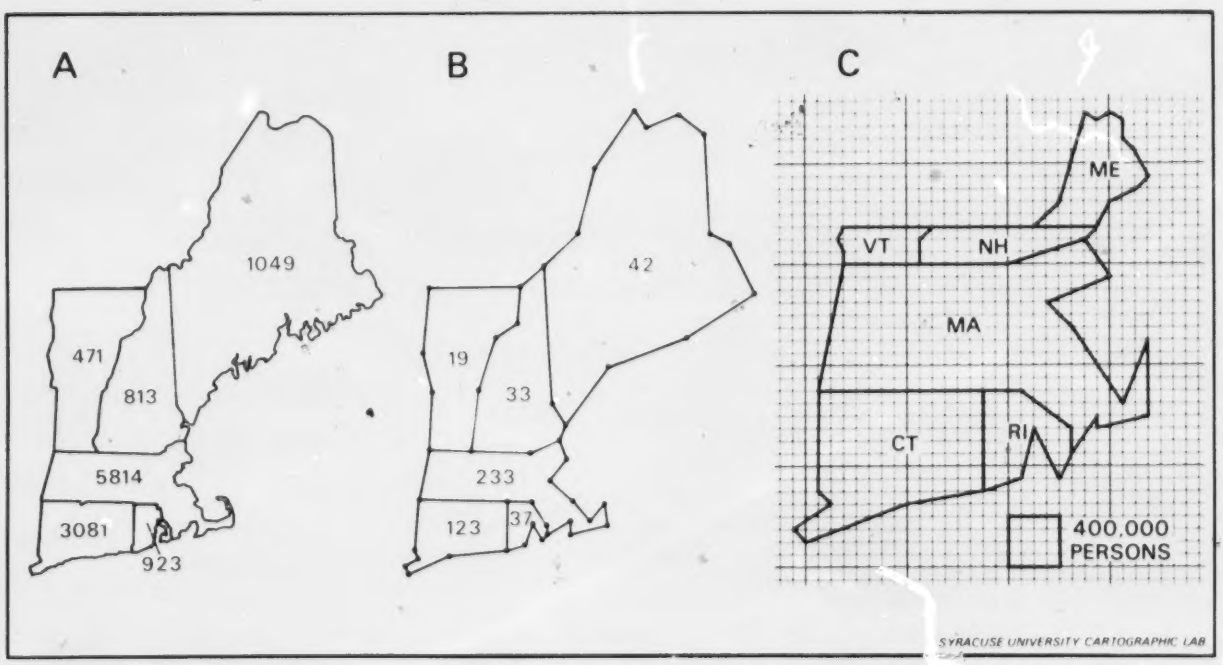

Figure 12. Stages in the construction of a contiguous area cartogram.

nor so large that all of New England would be compressed into a shapeless rectangle. Apply the same constant to find the numbers of grid squares for the other five states (Figure 12-B).

Transfer the distorted shapes to the square grid, beginning with a state near the center of the region. Adequate space must be available on the sheet for the other states and for the unused space needed if their shapes are to be portrayed realistically. Massachusetts, for instance, is to have 233 blocks, but make allowance for the 160 blocks of Connecticut and Rhode Island to the south and for the eastward extension of Maine. Experiment with different distorted shapes to approximate the true shape and to maintain the correct number of cells within the outline. An areal unit can be built up through the accretion of rectangles and triangles, the combined areas of which should match the number of grid squares specified for the state (Figure 13). Use of triangles permits diagonal boundaries and avoids blocky shapes. A triangle's area can be determined readily by dividing the area of the rectangle that encloses it by two. Thus a triangle two cells wide and three cells tall has an area of three.

In this example, Connecticut and Rhode Island are added below Massachusetts with little difficulty (Figure 12-C). Vermont and New Hampshire, however, are problems because population density is lower in northern New England than in Massachusetts. Since contiguity (sharing common boundaries) is to be preserved as an important supplement to the shape cues, these two states are mapped with relatively small northward extents. Although several cue points must be sacrificed, New Hampshire's Atlantic shoreline is preserved. Since Maine is contiguous only to New Hampshire, the essence of its shape can be retained with little difficulty. Finally, an area legend or *anchor stimulus* is added so that the reader can relate area on the cartogram to numbers of inhabitants; since 25,000 people are represented by one grid square, 16 cells (4 × 4) represent 400,000 people.

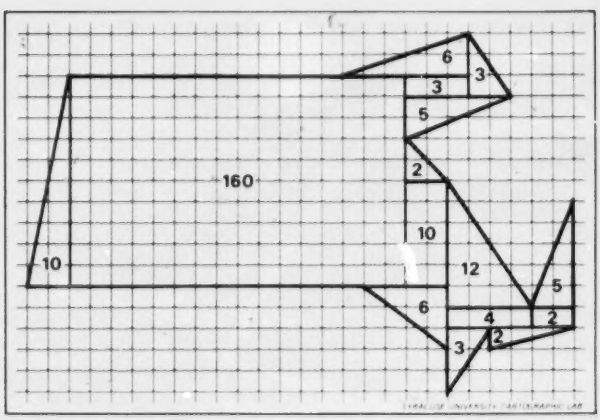

Figure 13. Reconstruction of the Massachusetts outline by adding rectangles and triangles.

Not all contiguous area cartograms can be constructed as readily as this one. Extreme variations in density make the preservation of both shape and contiguity difficult. A cartogram based on the populations of Canadian provinces and territories, for example, cannot portray adequately the Yukon and the Northwest Territories, which had 1966 populations of only 14,000 and 29,000 respectively. Furthermore, no matter how accurately the generalized shapes of some areas might be rendered, the cartogram is largely ineffectual if the original shapes of these areas are unfamiliar to the reader. Unfamiliar outlines are common with census tracts, minor civil divisions (townships, towns, boroughs, and villages), and even counties. Although labeling or including a standard map as a legend or inset might help in some instances, a large number of areal units or extreme density variations might preclude legible labels. Thus, the previous experience of the map reader and the mapped phenomenon itself are constraints on the utility of cartograms.

If contiguity is sacrificed, shape can be preserved in much greater detail. The resulting *noncontiguous area cartogram* can be constructed with the aid of a projector or can easily be drawn on a line plotter controlled by a digital computer (Olson, 1976). The areal unit with the greatest density is usually chosen as the basis for the scaling, and the areas of all other enumeration districts are scaled downward in proportion to their numerical values. Each areal unit is still centered about its original centroid on the base map, but most outlines contract inward (Figure 14). The result is a proportional symbol map where actual shape determines the form of each symbol. Density variations cannot inhibit the effectiveness of this type of cartogram unless some units are allowed to collapse to a mere dot. Yet, even if this should occur, these dots are meaningful symbols with meaningful locations relative to the other symbols on the map.

Distance Transformations

Maps are not the only distortions of distance. Since few roads are aligned with great circles, the highway network distorts the space man uses. Even airline routes are not usually direct because many flights detour somewhat from relatively straight routes to serve intermediate airports, and because air currents and safety demand departures from great-circle routes. Furthermore, distance, whether direct or circuitous, is but one method of describing the separations of places: movement over space of persons, merchandise, or messages is affected by distance, time, and cost. By telephone, City Hall is as close as one's next door neighbor. Yet, because of socioeconomic and cultural differences, social services, such as legal advice and medical care, might be inaccessible to low-income families even when lawyers and physicians are easily accessible by bus

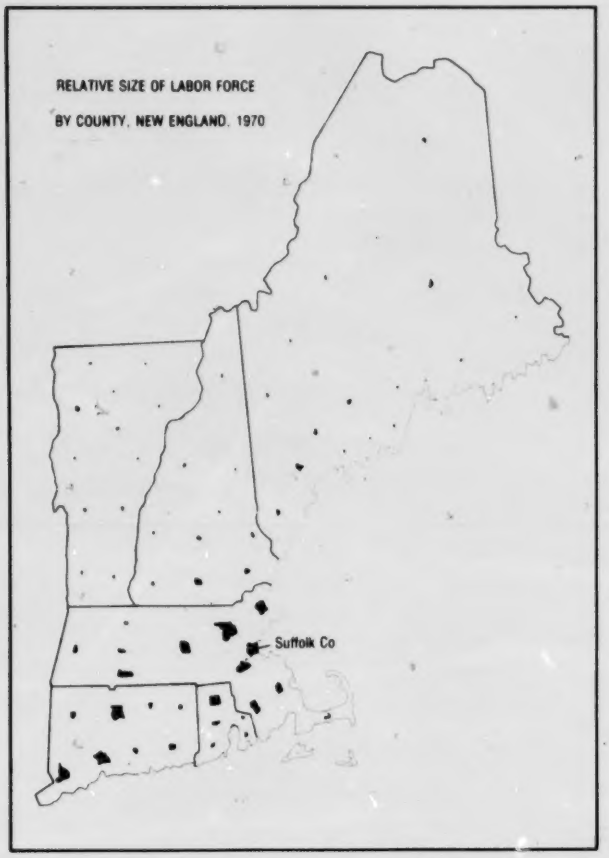

Figure 14. A noncontiguous area cartogram (from Olson, 1976). Reprinted by permission of the Association of American Geographers.

or telephone. This social distance is very real, although not readily measured, and explains why, for example, a ghetto youth might make a substantial detour around another group's turf.

Travel distance, travel time, transportation and communication costs, and social distances can all be mapped. Although the relative positions of points can be reconstructed from distance or dissimilarity measures by multidimensional scaling methods, a digital computer and a relatively complex program are required (Tobler *et al.*, 1970). When the map is to focus on a single place, however, its construction is relatively uncomplicated. A base map, blank sheet of paper, pencil, and measuring scale are the only materials required. The focal point and the places separated from it by a space distortion, such as driving time, are first located on the base map. Then radials are drawn from the center point *X* through and beyond the peripheral locations (Figure 15-A). Next, an appropriate scale is used to relocate these places on their respective radials (Figure 15-B). Finally, for the convenience of the reader, circular arcs are drawn at selected intervals and labeled so that a place's position relative to the focal point can easily be related to the distorting distance, time, or cost (Figure 15-C). Although not required, polar coordinate graph paper, which has evenly spaced concentric circles, is helpful in producing this type of map.

Interpretation of these distance-transformation maps, which are also called *linear cartograms*, is straightforward. In the previous example, for instance, places less directly connected by road with point *X* are displaced outward relative to places linked more directly with *X* (Figure 15-A and C).

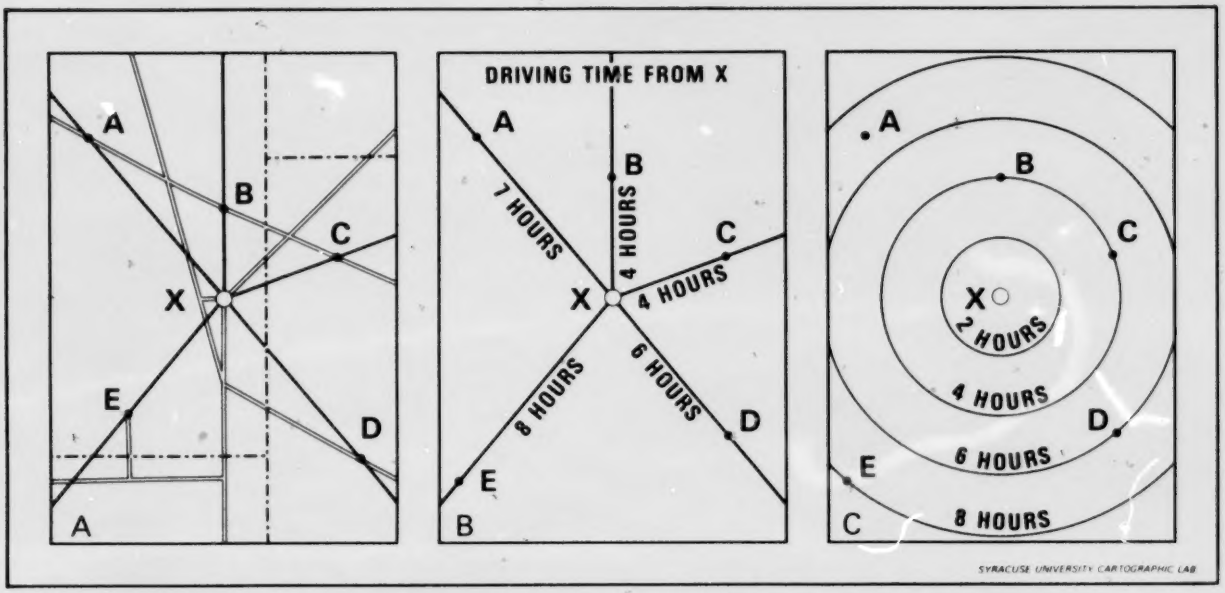

Figure 15. Stages in the construction of a distance-transformation map.

This method can be even more useful when comparing two or more phenomena. Different distortions of distance from Syracuse, New York, for example, result from telephone rates and airline fares (Figure 16). Since, on a distance basis, intrastate telephone rates are higher than interstate rates, a call to New York City costs more than one to Seattle. Binghamton and Watertown, both within New York State, also have higher rates than their distances from Syracuse would suggest. Airline rates, which reflect both flying and terminal costs, are more closely related to great-circle distances. Yet Binghamton, with no direct flights from Syracuse, is "farther away" than New York City in commercial aviation space. Other variables can be portrayed, such as the cost of mailing a first-class letter, which would equalize all destinations by placing them on a single concentric circle around the focus. Moreover, this approach can be used to illustrate changes over time as rates increase and transportation networks develop further. The method is simple and direct, and the reader can readily comprehend the map's meaning.

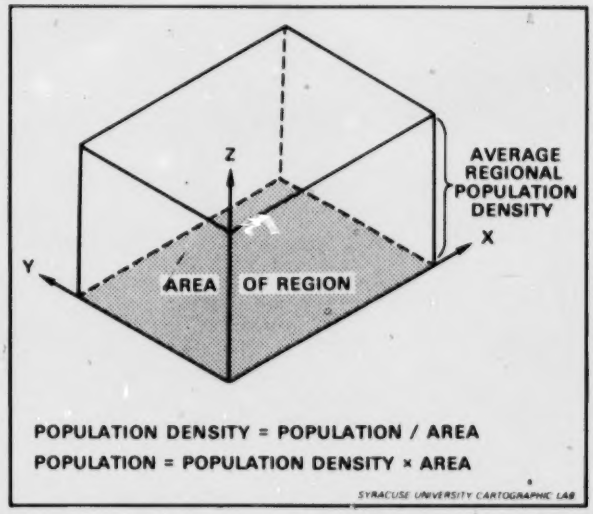

Figure 17. Prism representing population as a volume and population density as its height.

Stepped Statistical Surfaces

A map of population distribution is, in a sense, a view of the total number of people within a region where density varies from place to place. For a homogeneous region, total population can be thought of as the volume of a three-dimensional prism (Figure 17). The two horizontal dimensions, X and Y, describe the region's land area, and the vertical dimension Z is a scale for average regional population density. The formula for the volume of a prism—area of the base multiplied by height—thus becomes area times population density. Since population density is measured as number of people divided by area, the volume is simply the number of people in the region.

People, of course, are not uniformly distributed over space. Thus the surface of a three-dimensional

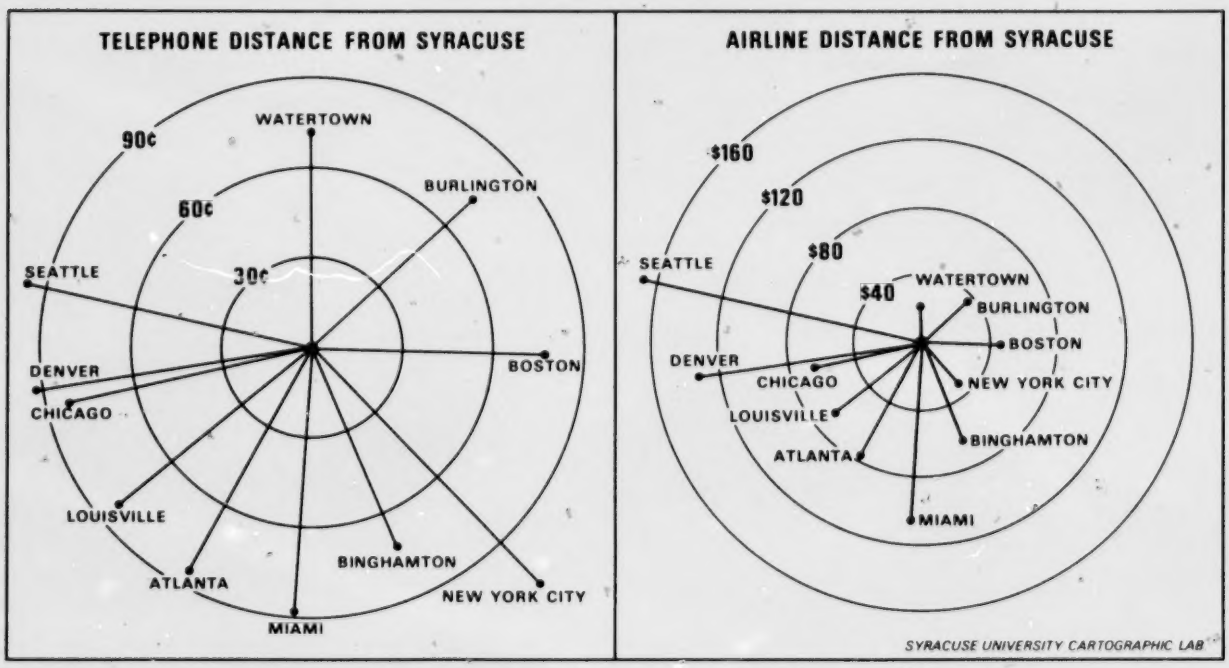

Figure 16. Distance-transformation maps focused on Syracuse, New York.

object representing population density is not a horizontal plane. Areas with high concentrations of population should appear as peaks, whereas large, sparsely populated parts of the region ought to resemble lowlands. These three-dimensional variations of density can be represented by either a smoothed or a stepped surface (Figure 18), and various methods can be used to yield appropriate levels of generalization (Cuff, 1975). In the specific case of a stepped surface, however, each county, township, or other census division is a separate prism with a height proportional to its population density.

Three-dimensional views can be plotted rapidly by a digital computer driving a high-speed pen plotter. Plotter mapping programs, such as SYMVU (Schmidt and Zafft, 1975), permit the cartographer to vary orientation, vertical scaling, height of the vantage point, and map scale. Perspective views, in which more distant points have smaller scales because they are farther away from the viewer's eye, are possible, but isometric views, with no similar scale distortion, can be drawn more easily than perspectives. Isometric-orthographic graph paper, available in most stores selling engineering supplies, also aids in the manual construction of an isometric stepped surface.

The procedure is relatively simple. First, trace the regional outline and internal boundaries onto a sheet of square-grid graph paper (Figure 19-A). The relative orientation of the grid lines and boundaries is important since, in this example, the area is to be viewed from the lower right; places closer to the upper left corner of the grid will then appear toward the rear of the stepped surface. Next, transfer the boundaries by eye to the isometric grid. Note that the squares are represented by diamonds on the isometric-orthographic paper. When the rectangular frame of the base map is transferred to this grid, however, it will still have the same number of divisions to the left and right of the foreground point (indicated by the arrow) that it had on the square grid (Figure 19-B). Relocate end points of straight and curved lines on the isometric grid by counting the number of divisions these points lie from the left- and right-hand edges of the frame around the region. Straight lines on the square grid remain straight on the isometric grid; simply connect their end points. Transfer curved lines by carefully noting the relative distances between intersections where they cross grid lines. If a boundary line meets a grid line halfway between two intersections on the square-grid paper, for instance, it will cross the isometric grid line midway between the corresponding nodes.

After redrawing the boundaries on the isometric grid, use the orthographic grid (perpendicular to the view and to the drawing surface, i.e., vertical lines on the graph paper) to position the tops of prisms at appropriate distances above their bases. A vertical scale drawn along a vertical orthographic grid line specifies different possible heights for the prisms (Figure 19-C). The horizontal lines can be used as counters in determining how far upward along the vertical lines the base points need be projected to form the top of a prism. Once the end points of the base have been duplicated at the elevation determined by the vertical scale—six units upward for the area in the background of the example—use the isometric grid lines to draw an exact replica of the prism's base. Then connect the top and base positions of the end points with vertical lines.

This process is repeated for the other areal units. In this example, the outline toward the right of the diagram is projected upward three units indicating that its population density is half that of the place in the background (Figure 19-D). Finally, all line

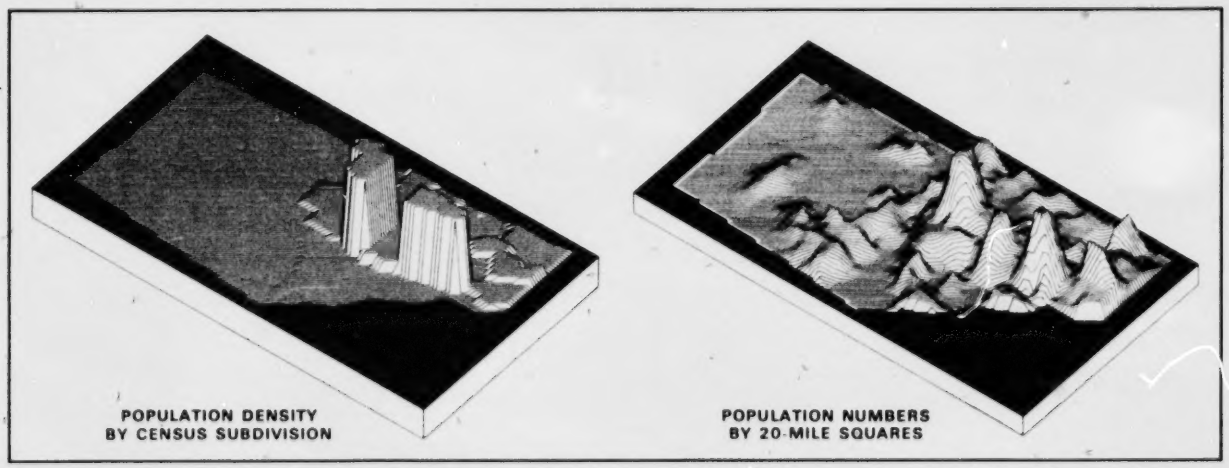

Figure 18. Stepped (left) and smoothed (right) isometric views of Alberta's population distribution (from Cuff, 1975). Reprinted by permission of the Department of Geography, University of Alberta.

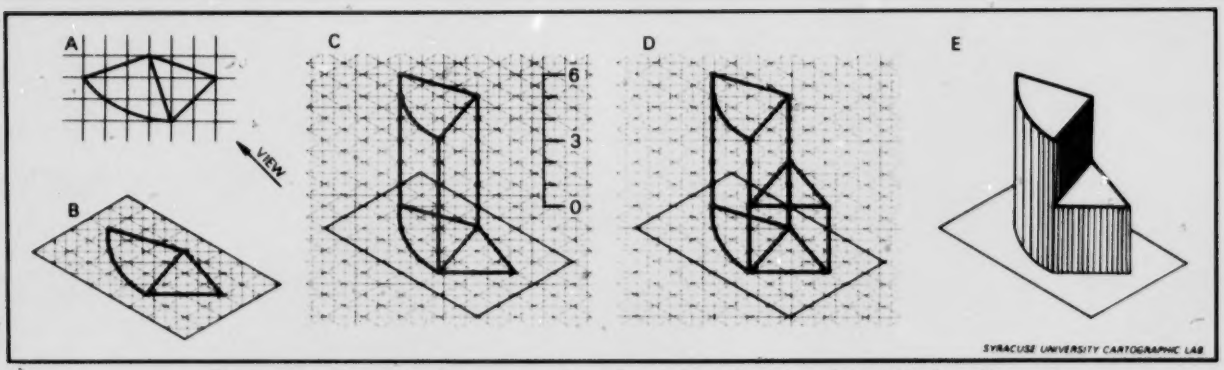

Figure 19. Stages in the construction of an isometric stepped statistical surface.

segments hidden from view are eliminated and shading is added to enhance the three-dimensional effect (Figure 19-E).

As with all mapping techniques, isometric stepped statistical surfaces have limitations. The most serious difficulties result when the surface has a number of extreme lows or highs or when an inappropriate viewing angle is chosen. For example, a three-dimensional view of physician-population ratios for the New England states with Connecticut and Rhode Island in the foreground results in the complete blocking of New Hampshire, a state less well endowed with M.D.'s than Massachusetts (Figure 20). Although a view from just south of east would at least provide a glimpse of New Hampshire, the reader might not readily recognize this state's short coastline between Massachusetts and Maine. Furthermore, a more irregular surface might not have any angle from which one can view all areal units. In instances where the reader need be provided with only a general impression of the relative locations of low values, blocking of one prism by others might not preclude using a three-dimensional view. Consequently, the map author must consider both the needs of the reader and the spatial pattern of the data in determining not only viewing angle but also whether or not to use this method at all. When an acceptable viewing direction exists, however, the isometric surface can provide a clear, striking visual impression of reality.

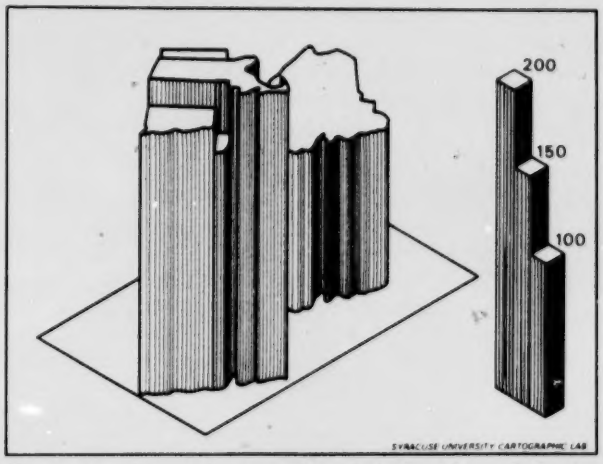

Figure 20. Isometric stepped statistical surface of physicians per 100,000 people, New England States, 1967.

IV. CLASSIFICATION AND CHOROPLETHIC MAPS

Choroplethic maps present a convenient solution to the hidden-area problem of isometric stepped statistical surfaces. Instead of viewing the surface from an oblique direction, a vertical view obviates the removal of hidden lines. The three-dimensional effect is lost, but area shading symbols supplant the heights of individual prisms as a means of portraying differences in value (Figure 21). Taller prisms, representing higher data values, are shown only with their bases filled with a relatively dark area symbol, whereas shorter prisms are depicted by comparatively light gray-tone screens within the outlines of their bases.

Classification Error

A limited number of gray-tone symbols is commonly used, and the areal units must be grouped into categories. Because the number of areal subdivisions almost always exceeds the number of shading symbols employed, places with similar values can be combined into a single mapping category represented by the same area symbol. The resulting classification is akin to representing each area assigned to the same category by an isometric prism with a height proportional to the mean value of the class (Jenks, 1967). As such, choroplethic classification is another form of cartographic generalization and another source of error.

Since categories should not overlap in value, adjacent categories are separated from each other by class breaks. A *number line*, along which all places are plotted as points, is a useful representation of both the data values and the divisions between classes. Since different locations for the class breaks will yield different classifications and different map patterns, a choroplethic map is but one of a large number of possible choroplethic maps that can be produced for the same variable (Figure 22).

Compact classes, in which the values are relatively similar, are generally desirable, since placing units with greatly dissimilar values in the same category increases classification error and might lead the reader to believe that these areas, linked on the map by a common symbol, are alike. In many instances, therefore, natural breaks separating clusters of points on the number line are preferred divisions between mapping categories. Since natural breaks are not always obvious, however, other classification methods, such as quantities, which assign approximately the same number of areas to each class, and equal-step intervals, whereby the range between the lowest and highest values is divided into equal parts, are often used (Figure 23). Quantiles provide readily understood legends; in the case of four classes, for example, each category contains 25 percent of the areal units because the reader can readily relate the categories to frequency of occurrence. The legends for equal-step categorizations can also be read easily because the high and low ends of the total range of data values can be shifted outward to provide round-number class limits, such as 0-9.9, 10.0-19.9, 20.0-29.9, and 30.0-40.0. Both quantile and equal-step classifications, however, might subdivide naturally homogeneous categories and thereby decrease the accuracy of the map.

Classifications are sometimes based on a variable's *mean* (arithmetic average) and *standard deviation*. The latter is a measure of the dispersion of data values about the mean and can be used to

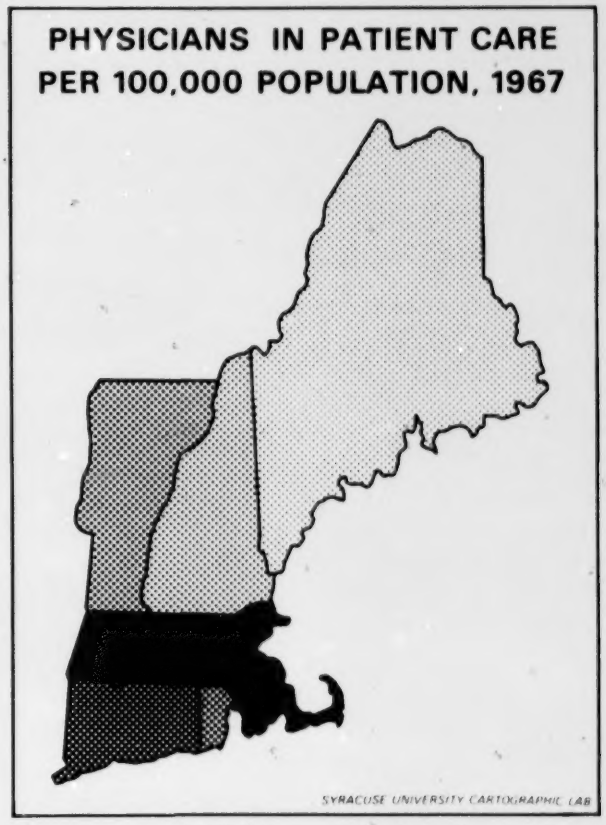

Figure 21. Choroplethic representation of a statistical surface. Compare with Figure 20.

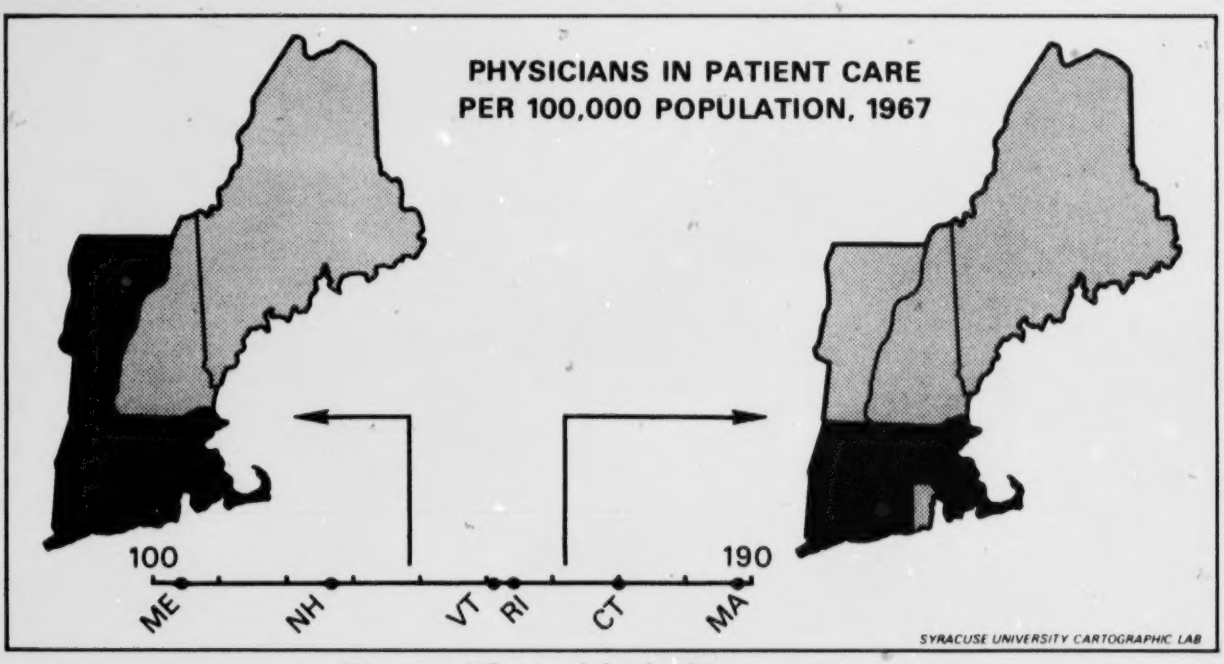

Figure 22. Influence of class breaks on map pattern.

determine the interval between breaks located, for instance, at 0.5 and 1.5 standard deviations above and below the mean. This type of classification is useful for locating places with extremely high or low values, but it might also ignore natural breaks.

The same distance between points, however, is not always equally significant everywhere along the number line. For example, on a county-unit map showing the distribution of nonwhites in the United States, the ten-point difference between five percent and 15 percent is far more important than the difference between 55 percent and 65 percent. Since few counties have this high a proportion of nonwhites, grouping all counties with percentages of nonwhites over fifty into a single class results in no appreciable loss of detail.

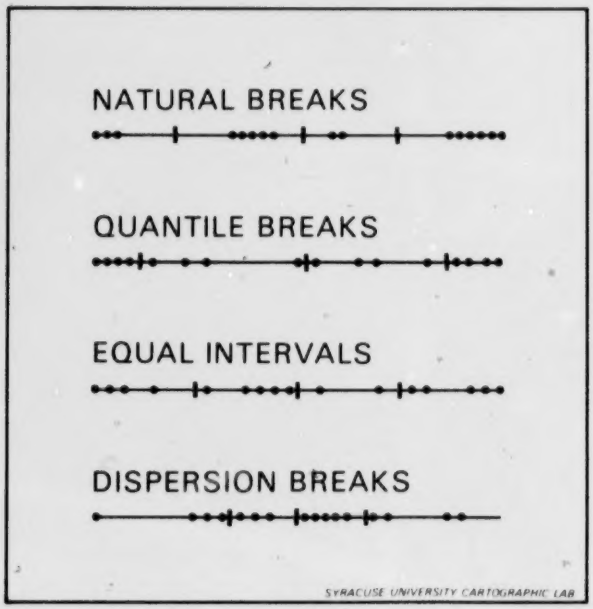

Figure 23. Number line illustrating some different methods of determining class breaks.

Some class breaks are more inherently meaningful than others. For a map of nonwhite population a break at 12.5 percent is appropriate since this is the percentage of nonwhites in the national population. Similarly, on a map of population change, percentage breaks differentiating gains from losses and modest gains from gains in excess of the national rate of growth may be more useful to the map reader than breaks between internally homogeneous mapping categories (Schnell and Monmonier, 1976). The intended purpose of the map, therefore, should be a major determinant of a classification's relative merits.

Pattern and Perception

Classification of areas is, of course, helpful to the map maker who need employ only six or fewer different area shading screens. Choroplethic classification also assists the map reader, since it presents a regionalization of the mapped variable. For the reader interested primarily in the values for individual areal subdivisions, however, a pen plotter and computer can produce screens with gray tones

anywhere along a continuum from white to black (Tobler, 1973). This user might be better served by an *area table* in which each unit's numerical value is printed within its mapped boundaries, since continual referral to the legend of a continuous-tone map would be necessary. Of course, choroplethic maps without classes might obviate misinterpretations resulting from the assumption that a mapping category is more homogeneous than it really is. Furthermore, the reader would be able to compare differences along boundaries and obtain a more accurate impression of whatever cliffs would appear on a stepped statistical surface. The reader would also be able to regionalize visually and to determine what areas belong to the same region (Figure 24).

But is this so? Although a visual regionalization is certainly possible, the reader might miss important aspects of the pattern that the map author would want to highlight. A well-designed choroplethic map with classes would more likely assure the desired interpretation if the map author has a definite message in mind. Some thematic maps should be the graphic equivalents of a news bulletin rather than the spatial analogs of a poem, subject to the whim or mood of the reader. The map maker must determine how broad or narrow the map's message is to be.

Although classification in choroplethic mapping gives the map author greater control over the inevitable distortion, the author must be aware of the reader's limited capacity for decoding graphic information. One constraint is imposed by some readers' inability to differentiate readily and with consistent results among more than eleven different gray tones (Jenks and Knos, 1961:331). Actually, no more than six categories are recommended, even though a specialized audience of planners or researchers might be able to cope with a greater number of classes (Schultz, 1961:225-26). If more than six categories are contemplated, the author should reevaluate the map: the theme should probably be subdivided and presented on two or more maps.

An increase in the number of categories usually increases the complexity of the mapped pattern. Although complexity cannot be measured adequately by any single index, a complex map might be described as having 1) a relatively large number of *map regions* (contiguous areas assigned to the same class); 2) substantial differences in the sizes of these map regions; and 3) little spatial regularity (Monmonier, 1974). The spatial consistency of the data and the locations of breaks between class intervals are other factors influencing complexity. Although little can be done to minimize the variable's contribution to pattern complexity—aside from generalizing the data with trend-surface analysis (Chorley and Haggett, 1965) or some other spatial filtering method (Tobler, 1969) before map-

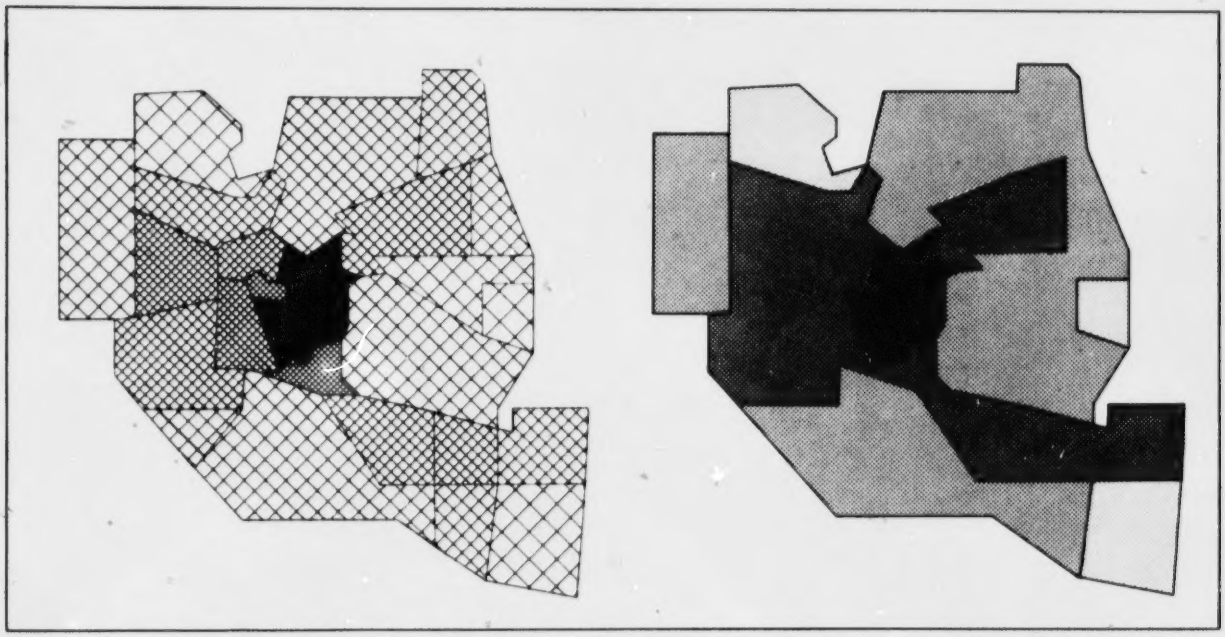

Figure 24. A choroplethic map without class intervals for census tracts in Ann Arbor, Michigan (left, from Tobler, 1973). The map at the right is a five-class regionalization of the same distribution. When no class intervals are used, some of the darker continuous-tone area symbols might be indistinguishable from one another when photographically reproduced. Map at left reprinted, by permission, from *Geographical Analysis*.

ping—imposing some classifications on the data might adversely fragment a distribution when other sets of class breaks would yield a much simpler pattern (Figure 25).

Is complexity always undesirable? Here purely geometric complexity must be distinguished from complexity related to the map reader's knowledge of an area. A pattern that might appear highly disorganized to map readers unfamiliar with a region might be especially meaningful to a more knowledgeable user who is, for instance, able to associate high values with urban centers and low values with pockets of rural poverty. Thus, a pattern is only unduly complex when it defies the reader's attempts to recognize order in an assemblage of graphic symbols. If a map is readily related to an accepted geographic regionalization or another known spatial distribution, it is not too complex despite its possible high degree of geometric complexity. When the map reader is unable to relate the map's pattern to either a preexisting conception of the area or to some geometric framework, such as a plane sloping to the southeast or a distorted dome around some urban center, the map's complexity might then be too great. Even here, however, the author might intend for the map to demonstrate the absence of a recognizable geographic pattern, and in this case a high level of complexity is justified. When some meaning could be decoded from a map if its pattern were simplified by choosing another set of class breaks, however, the reader's recognition time or likelihood of correct interpretation may be decreased. This adverse effect of complexity on map comparison (Muehrcke, 1973) might reasonably be extended to situations where one of the two images is in the reader's mind, rather than on a sheet of paper. Moreover, if the map author wants the map reader to retain a clear mental impression of a distribution, a simplified pattern would be preferred (Arnheim, 1976:9).

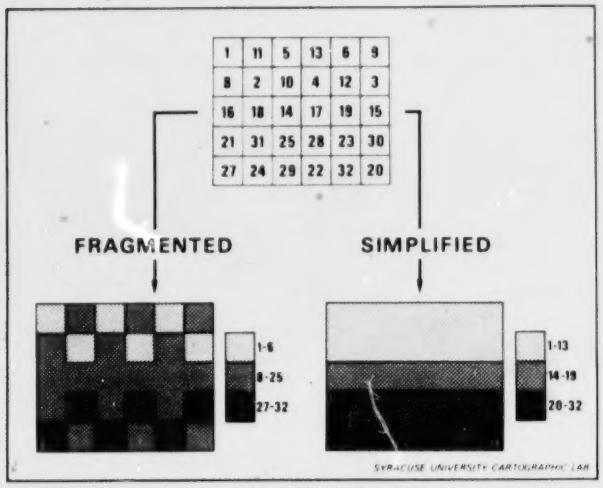

Figure 25. Fragmented and simple patterns produced by different classifications of the same data.

One method for reducing complexity is trial-and-error experimentation with different mapping categories. These actions of the cartographer, however, are *generable behavior*, which can be decomposed into a finite number of discrete steps and simulated on a digital computer (Monmonier, 1976b). Rather than attempting to follow precisely the steps a diligent cartographer might take in reducing unwanted complexity, the computer can be given a program not unlike those used by geographers and planners to determine optimum locations for service facilities, such as health clinics and industrial warehouses (Monmonier, 1973a). These *algorithms* (step-by-step procedures for problem-solving) attempt to locate centers—or in the case of mapping, class breaks—by optimizing the value of an *objective function*. In statistical mapping an objective function to be minimized would be some measure, or combination of measures, of pattern complexity (Monmonier, 1974; Muller, 1975a and b). Experiments have indicated that map readers are able to judge relative map complexity measured in a variety of ways (Olson, 1975a; Muller, 1976), thereby validating the use of these measures in an objective function. As with other optimization techniques, algorithms for selecting class intervals also impose mandatory or artificial constraints that obviate the consideration of inappropriate solutions, such as overlapping and empty classes or classes with too few areal units. Optimization algorithms have been developed to reduce the fragmentation of map patterns (Monmonier, 1972a) and to maximize visual association either with another map (Monmonier, 1975) or with a known regionalization (Monmonier, 1976a).

Trade-offs usually exist between accuracy and simplicity: normally a map cannot be made less complex without sacrificing within-class homogeneity. Thus, optimization algorithms designed to reduce complexity must be used with probity so that a desired pattern not really present in the data is not unjustifiably imposed. For some geographic distributions the improper use of optimization techniques might lead to a deliberate graphic falsehood. Yet nature tends to be orderly, and the data value for a place tends to resemble those of neighboring areal units more than it approximates values at more remote locations. This phenomenon, called *spatial autocorrelation*, gives many map patterns an inherent simplicity—a simplicity that can attain its optimum graphic expression if an appropriate computer algorithm is invoked. Moreover, when nature is complex or when an attempt is made to impose an unrealistic pattern on a map, the algorithm can be defeated easily by the data. Furthermore, should doubt exist about the classification error induced by forcing a simplified pattern, the accuracy of the simplified map can be compared with that of the

map for the same data but with the least possible error in its categories. In fact, the first widely publicized use of an optimization method for choroplethic mapping was the algorithm developed by Jenks and Caspall (1971) to find the class breaks with the most internally homogeneous categories. Further development of cartographic optimization techniques is likely to involve subject-testing in finding objective functions more directly related to what the reader sees so that, where possible, the clearest and most effective graphic image is given the map reader.

Cartographic Correlation

As implied in the previous section, choroplethic maps can be used in pairs to illustrate an association between two geographic distributions. Two variables might then be said to be related if their mapped patterns are similar. If the same areal units are employed for both maps, the correlation can be portrayed graphically by either a map or a scatter diagram (Figure 26). When the correlation is strong, the points plotted on the scatter diagram will exhibit a well-defined trend. The mapped patterns provide a geographic supplement to the scatter diagram and permit the reader to note areas of agreement and disagreement between the variables.

Correlations can also be represented numerically by a correlation coefficient—an index that ranges from 1.0 for a perfect direct correlation, through 0.0 for no correlation, to −1.0 when a perfect inverse relationship exists. Although many coefficients of correlation have been developed, the most common measure is Pearson's product-moment correlation coefficient. This index reflects the direction of the relationship with its sign—positive if an increase in X produces an increase for Y and negative if an increase in X resuits in a decrease for Y. Its absolute value measures the strength of the relationship: values close to 1.0 or −1.0 occur if the scatter of points can readily be approximated by a straight line, whereas values close to 0.0 result when the points do not suggest any linear trend (Figure 27). Yet a correlation can be strong without being linear. In fact, curvilinear relationships are common, particularly when a variable has an absolute lower or upper limit, such as 0 or 100 percent. Thus reliance solely on this linear correlation coefficient might lead to a serious underestimation of the strength of a curvilinear relationship.

Estimating the degree of correlation with maps, scatter diagrams, or correlation coefficients requires data appropriate to the researcher's objective. If the goal is to determine the association between health-care availability and mortality, for example, suitable measures must be chosen for both phenomena. Physicians might be selected as an expedient surrogate for health care, but other medical professionals, hospitals and clinics, and payment plans are also relevant. Medical doctors engaged in research or administration should be omitted since these physicians have little direct contact with patients. Moreover, if a map is to show the relative availability of doctors, the number of physicians should be adjusted to population size. Size standardization, which can also be based on land area, size of labor force, and other factors relevant to a mapped distribution, is usually necessary since areas with larger populations, more farmland, or larger numbers of jobs will have higher values for many variables solely because of these aspects of size. As a result, the adjusted mapped patterns will generally be different from patterns produced without size adjustment (Jenks, 1976). Furthermore, if one variable

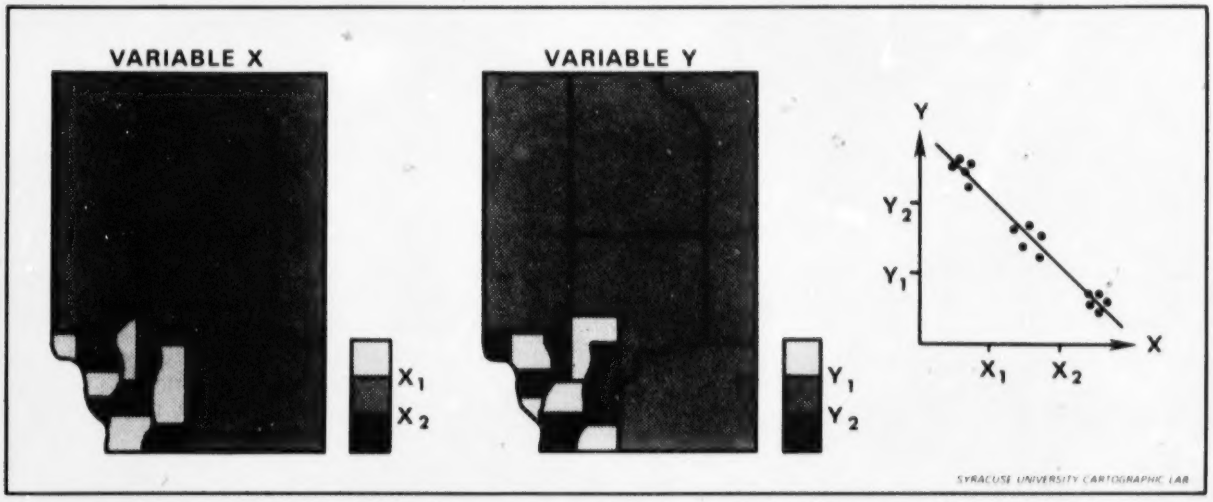

Figure 26. Paired maps and a scatter diagram representing the correlation between variables X and Y. Note that variation in the size of the areal units produces an invalid visual association between X and Y.

is adjusted for size differences, the other variable should also be converted to a measure, e.g. ratio or median, independent of the areal units' extent or population.

In the case of mortality, size adjustment might also reflect geographic differences in age structure. Places with greater proportions of elderly are more likely to have higher ratios of deaths to population. Thus demographic standardization, whereby an area's actual number of deaths is adjusted to the number of deaths expected from the national death rate and differences between the area and the nation in age, race and sex composition, is desirable (Armstrong, 1969). Even this correction might be inadequate to assure reliable data, since the boundaries of the areal units might have little relevance—nothing prevents people from seeking health care outside their county of residence!

Another source of data noise might be the year or years considered: small populations can exhibit substantial fluctuations in their death rates from year to year. These temporal variations might be stabilized if rates are averaged over a longer period of time.

The map reader's ability to estimate reliably the level of association is another limitation of cartographic correlation. The likelihood of an incorrect interpretation is particularly high when the areal subdivisions of a region vary greatly in both land area and the areas their symbols occupy on the maps. As an illustration, it is possible for a state to have 15 counties, most of which are clustered in one corner of the state (Figure 26). While interpreting the association between two variables, the reader might tend to ignore these smaller areal units and concentrate instead on trends present among the larger, more visible counties. Because these larger areas, as in the American West, might be sparsely populated, their trends could be substantially unrepresentative of those for most of the region's population.

The level to which data may be aggregated presents another problem: different types and degrees of spatial association can emerge if one maps a particular phenomenon in a state and uses counties rather than the minor civil divisions within these counties (Figure 28). This effect is likely to be more prominent when the mapped phenomena are not uniformly distributed throughout the larger areal units. As an example, consider two variables, only one of which yields a similar map for both counties and their minor civil divisions (the three central divisions). Let the values for the other variable, say, the proportion of the population in a particular demographic group, be rates that must naturally be recomputed when the smaller minor civil divisions are aggregated upward into larger mapping units (Figure 28). If some of the larger units have a single, relatively populous subdivision substantially different from their county's other areal constituents, the appearance of this less uniform variable and the resulting visual assessment of the correlation might be radically affected by the level of aggregation (Figure 29).

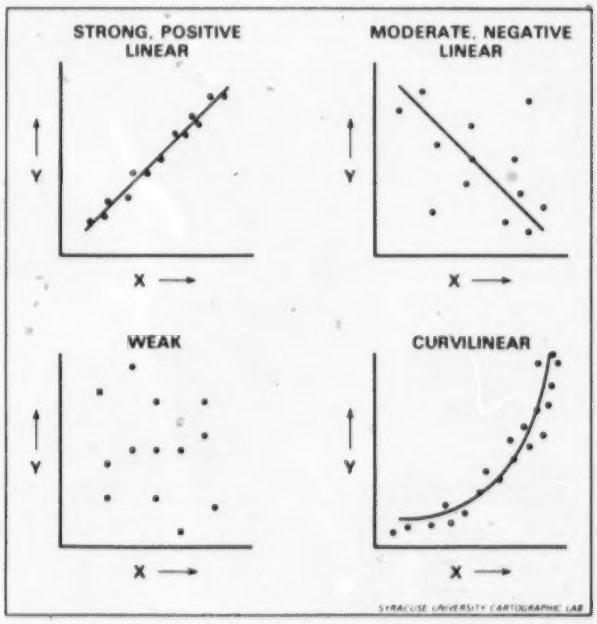

Figure 27. Scatter diagrams illustrating different correlations.

This influence of aggregation, also evident in the scatter diagrams and coefficients of correlation for the two variables, is usually not this great. Nevertheless, the risk of spurious correlations pervades much geographic research. One might prevent inaccurate conclusions by mentioning the specific areal units used in a statement of findings. Thus, "the unemployment rate varies inversely with the percentage of persons with a college education" should be followed immediately with the qualification, "at the county-unit level of aggregation." This type of tempered statement also clearly distinguishes an *ecological correlation*, based on areal aggregates, from an *individual correlation* obtained by using individual persons, farms, or industrial plants as the fundamental data units. In no event should a relationship obtained for areally aggregated data—even if the basic data unit is the city block—be applied to individuals. The unqualified declaration that "college-educated people have a lower rate of unemployment," if based on an analysis of choroplethic maps, would be a prime example of the *ecological fallacy* (Robinson, 1950).

Although the pitfalls of ecological correlation apply to both maps and correlation coefficients, a quantitative measure of association is an important supplement to a pair of maps from which the map reader is required to estimate the strength and trend of a relationship. The class intervals used with choroplethic maps confound even more the reader's

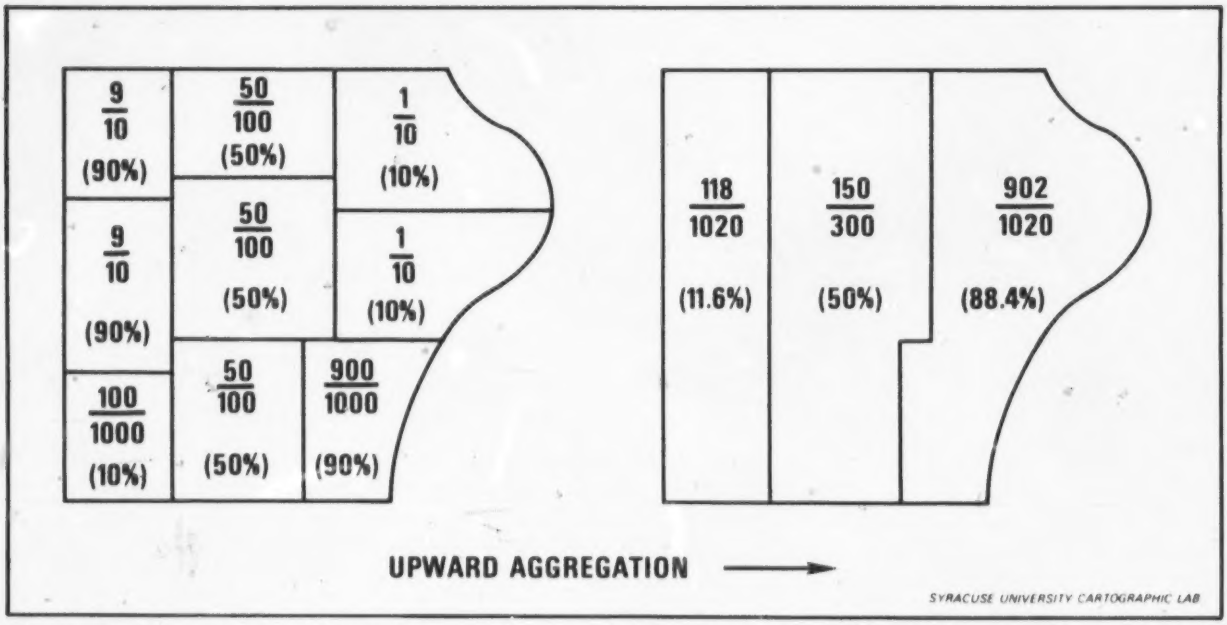

Figure 28. Effect of upward aggregation on rates computed for minor civil divisions (left) and counties (right) of a hypothetical state. When both numerator and denominator are added within the counties, the resulting rates might produce a substantially altered pattern for these larger aggregates.

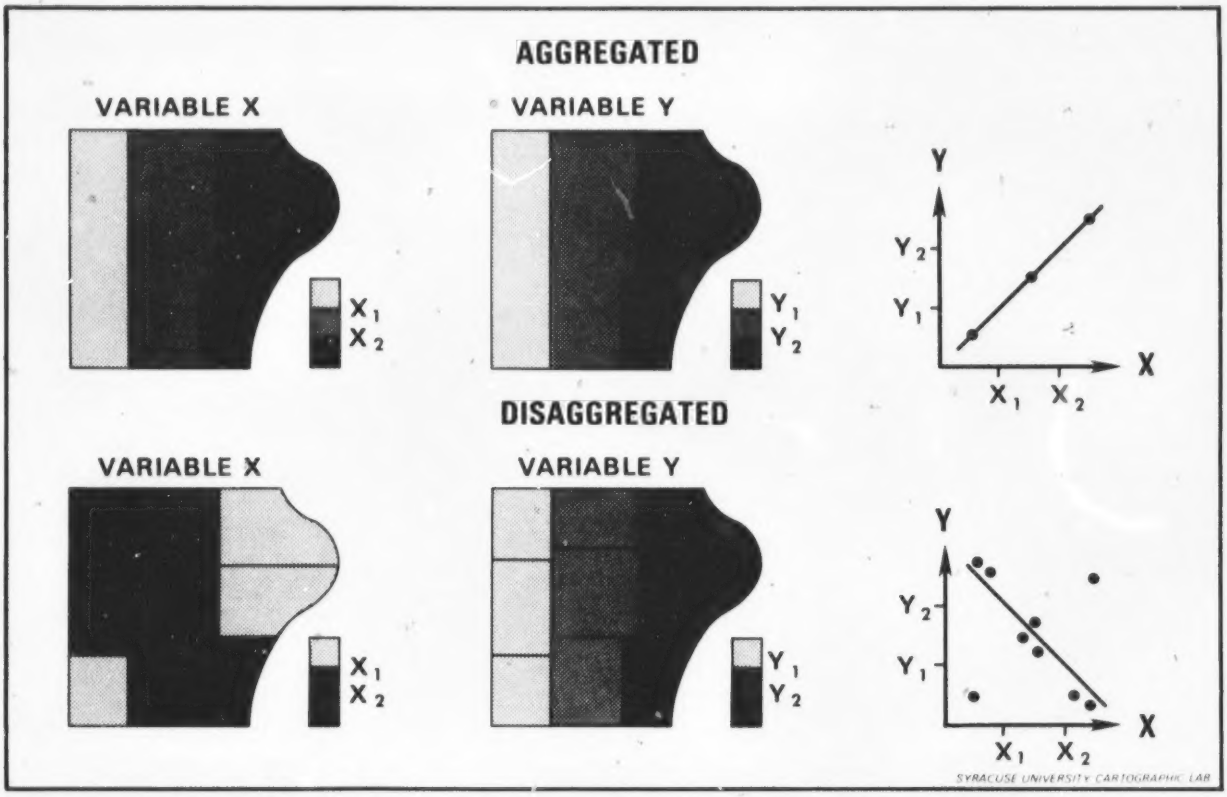

Figure 29. An extreme effect of upward aggregation on cartographic correlation and scatter diagrams. Variable X yields a different pattern when its rates are recomputed as shown in Figure 28.

task of obtaining an accurate impression of a correlation since not one, but two classifications are involved; either or both maps can now contribute to a misinterpretation. Moreover, if asked to estimate the relative correlations among more than a single pair of maps, the reader might be unable even to rank the relationships correctly if the correlations are similar in magnitude. Studies of users' abilities in judging the relative correlations between different pairs of maps also suggest that where the correlation is only moderate, errors are more frequent (Muehrcke, 1969:45-70). Furthermore, highly complex patterns are likely to thwart the reader's judgment still further. Even where different types of areal units are involved, sampling estimated values from both maps to provide a comparable data base and calculating a correlation coefficient from this sample can provide the map reader with a useful numerical supplement to the visualized association.

Because of the difficulty in estimating the magnitude of a correlation with maps, and also because the correlation coefficient is a convenient and necessary supplement to cartographic correlation when a significant correlation exists, the map should be assigned a more appropriate, purely visual role in demonstrating graphically the association between two variables. Here again optimization algorithms can be of use when the correlation is great enough

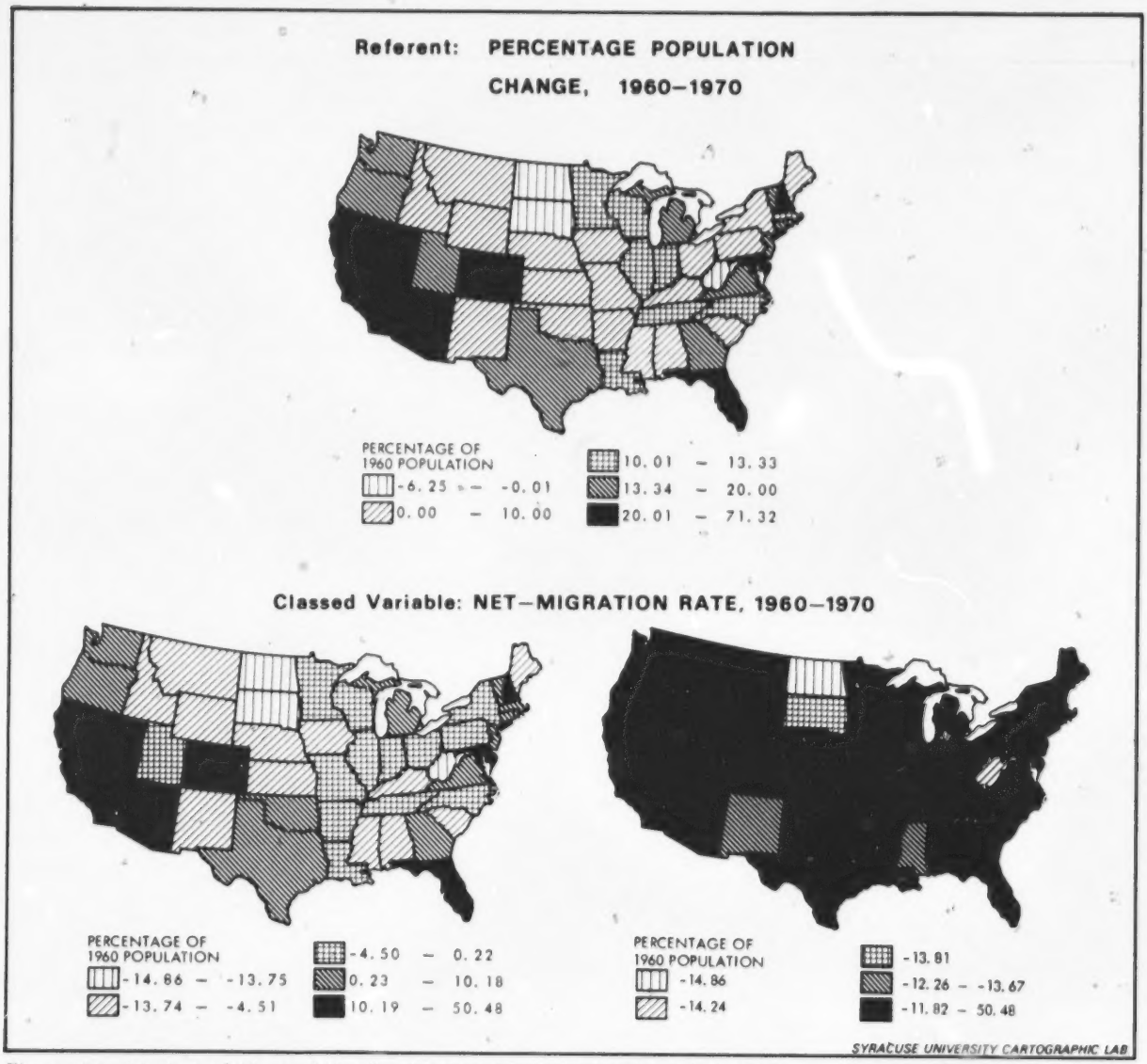

Figure 30. Maximized (lower left, after Monmonier, 1976a) and minimized (lower right) visual correlations with a referent variable. Maps at left and center reprinted by permission of *The Canadian Cartographer*.

to warrant graphic presentation, because objective functions can be defined to maximize the visual correspondence between maps (Monmonier, 1976a). Although the range of visual associations that different class breaks can produce for any one correlation can be great, the reader, where appropriate, can be provided with the strongest possible graphic representation of the association. Furthermore, in the interest of integrity, an optimization algorithm might also be used to yield the worst possible cartographic correlation. These best and worst examples might then be juxtaposed so that the reader can judge the validity of the author's findings (Figure 30)! But the combination of the best-case pair of maps and the correlation coefficient should be both adequate and effective.

Information Overkill

Associations often involve more than two variables. Although three or more maps can be placed within the same frame to facilitate comparison, the eye must jump from map to map much more frequently than when only one pair of variables is compared. This problem has led some map authors to superimpose several distributions onto the same map. This kind of solution, however, can present more problems than it solves because the reader is now asked to interpret a complex legend and differentiate among a larger than average number of area symbols (Figure 31). Despite their unquestioned utility for information storage, these multiple-variable maps are too complex for ready information retrieval.

A simpler answer—for the map reader, at least—is to recognize that multiple themes are present and to produce more than a single map. In fact, each area symbol used on the multiple-variable map can be the subject of a separate portion of the author's written text or oral presentation. Each of these subthemes, involving places that are similar for all variables considered, can be shown on a separate map that can be placed closer to the relevant part of the manuscript or appear on the screen only when these particular areas are being discussed (Schnell and Monmonier, 1976). Furthermore, a legend is no longer needed since the characteristics of the places highlighted by the map can be explained in the title or caption (Figure 32). Thus all peripheral material is removed, at least temporarily, from the reader's attention. Moreover, the much simpler area symbols now required permit the reader to examine internal boundaries with less distraction and thereby obtain a more thorough impression of the places' locations.

The map, of course, must be suited to the task required of its reader. If it is necessary for the reader to know that Type A states are usually adjacent to Type D states, this phenomenon should be presented as a separate theme on a single map, uncluttered by other significant aspects of the distribution.

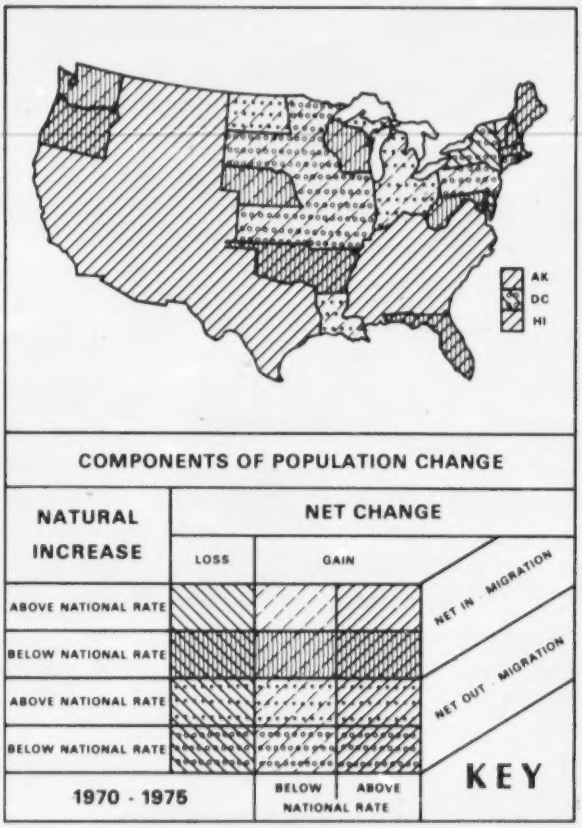

Figure 31. Portraying the association among three variables with a complex multiple-variable map. Note that the legend occupies more space than the actual map and that many of the area symbols in the legend are not even used on the map.

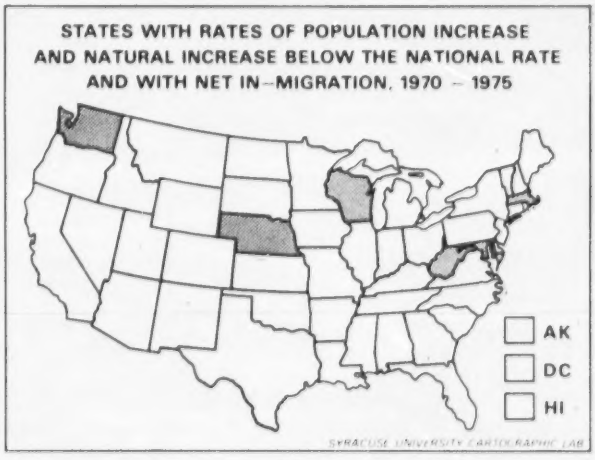

Figure 32. A simple single-theme map illustrating one aspect of the association among three variables. Six maps of this type can portray the pattern shown in Figure 31.

Choroplethic maps are not sacred cows, and the needs of the reader should not be subservient to the whim or workload of the cartographer. For some applications, *dasymetric* maps, which refine the existing choroplethic boundaries, can give a more accurate picture that recognizes nonhomogeneous enumeration districts (Wright, 1936). If the required supplementary data are available, a dot map might also provide a more refined representation of the same distribution (Dahlberg, 1967). An *isoplethic* map can be drawn by assigning the values for the areal units to their center points and then interpolating lines of equal value, such as contours, to give the distribution a smoothed appearance not encumbered by any internal boundaries (Mackay, 1951). Isoplethic maps emphasize gradients, but if the map is intended to highlight only differences between adjacent areal units, a regionalization displayed without area shading but stressing the significance of certain internal boundaries might be appropriate (Monmonier, 1973b). When the reader's attention is to be focused on only broad regional trends, spatial filtering can eliminate unnecessary visual noise and thereby enhance the important aspects of the distribution (Muehrcke, 1972:16-19). Generalization to facilitate trend detection might even involve mapping the distribution as a network of arrows linking chains of places with progressively higher data values (Monmonier, 1972b). The cartographic technique employed should always attempt to minimize decoding error.

V. PURPOSE AND DISTORTION

The previous chapter addressed some aspects of the use of maps for communicating the results of research. Geographic research, however, is merely one of a large number of different purposes for which maps are employed. Most map users, in fact, are exposed more frequently to maps with nonacademic objectives. This chapter discusses several diverse applications of maps by commercial and government organizations and by private individuals working outside academia. The examples presented here are intended both to indicate the numerous goals that might be served by maps and to illustrate that, whatever the aim, the map must be adapted specifically for a well-defined and feasible objective.

Route Planning and Route Following

Adults in a modern, mechanized, and mobile society, even if they have an excellent so-called sense of direction, find it difficult to travel in unfamiliar places without maps. Motorists use maps both to plan and to follow routes. Users of public transportation also employ maps to determine suitable carriers, to locate particular schedules in a timetable, and to plan transfers from one carrier to another. Even taxi passengers, who merely inform the driver of their desired destinations, consult maps in some cities, such as Washington, D.C., where fares are based not on mileage, but on the number of zone boundaries crossed. Of all possible types of maps, highway and street maps are used more frequently, more intensively, and with more frustration than other varieties.

Road maps, as a class, have two distinctly different purposes—route planning and route following. In order to plan a route a map reader need have only an up-to-date map or maps covering with adequate detail the area between origin and destination. Whether or not a map has sufficient information depends on the purpose of the trip, the specific needs of the traveler, and the route itself. If sightseeing is intended, the locations of historic landmarks, tourist attractions, parks, and similar features must be included. If the driver is towing a camper, camp grounds should be shown. If the trip is for business rather than pleasure, motorists welcome data comparing the driving times along different routes. When the route includes delays or detours because of maintenance or new construction, advance knowledge of these conditions is useful. Many road maps are obsolete, and many motorists prefer to have their routes planned by automobile clubs with access to the most recent maps and data on road conditions.

Maps adequate for route planning are often deficient for route following. Here the map reader is using the map under an entirely different set of circumstances than when planning the route at leisure. Routes are often followed in heavy traffic at high speeds in cars with discontented children, spouses, and pets, some of whom invariably have empty stomachs, full bladders, or both. As indicated by the fuel gauge, the vehicle might be hungry as well. Worse yet, its cooling system might be relieving itself of steam from an overheated engine. Nonetheless, the driver must concentrate on traffic and on highway signs and signals, and must also decide whether to turn left onto 17-K or right onto 17-M. It might or might not be safe to pull off the road, stop, and reexamine the map, and it is often tempting to take a quick glance at the map to clarify the route.

These hazards of in-transit map reading might be alleviated, in part, by a road map that does not need to be unfolded, reversed, and oriented. A practical solution, albeit one that cannot eliminate emotional stress or correct poor driving habits, is provided by the American Automobile Association's Triptik, a unique form of road atlas "prepared expressly for you." Maps covering the entire length of the journey are bound into one or more books with plastic fasteners so that the pages can easily be flipped over at the top (Figure 33). Individual maps, covering approximately 75 to 125 miles of the route along major highways between important cities or junctions, are arranged in sequence. These strip maps, longer than the average hand but far less bulky than an ordinary road atlas, include only the primary roads between the two end points, in addition to important highways crossing the routes. Symbols indicate the locations of gasoline stations, restaurants, "approved" motels and hotels, campsites, and places of potential interest to tourists. Mileage from each end point to significant intermediate points is given in the left- and right-hand margins. The map itself also shows mileages between interchanges and major intersections. Information not needed for route following is omitted and supplementary remarks about construction projects and areas of strict enforcement is rubberstamped onto the maps where needed. If a motorist decides upon a side trip en route, he or she need only turn over the strip map to find a centerfold map of a circular area surrounding the strip. These centerfolds, taken from a standard highway map and printed at a somewhat smaller scale than the strip map, contain extra details. When the strip map

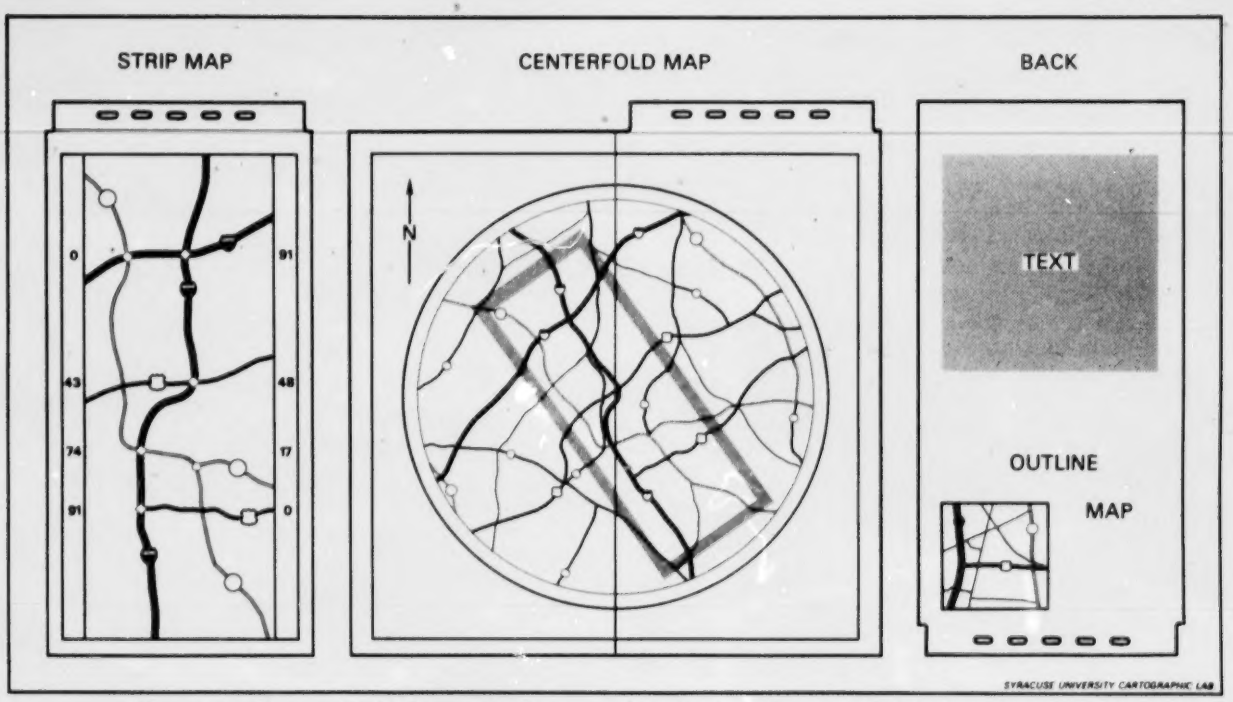

Figure 33. Format of a leaf in a Triptik prepared by the American Automobile Association.

is flipped upward, the driver finds on the back of the leaf one or more outline maps of medium-size and small cities in addition to a brief verbal description of these and other places of interest. Special pages with the same general format as the strip map are included for recreation areas, routes through major cities, and approaches to large metropolitan areas. The Triptik is an excellent example of maps designed for a specific purpose—following a route for a particular journey.

Triptik maps attempt to meet route-following needs by providing only those details most likely to be required by the driver. Road maps in general can present difficulties when they contain either too little or too much information (Morrison, 1966). The effective presentation of detail is, in part, a function of map scale. As a recent economy measure, oil companies providing free road maps are now using smaller scales, thus making their maps less a service to the driver than they once were. The use of these smaller scales might give some drivers eyestrain as they attempt to follow a thin blue line wandering among a multitude of place names. This cartographic recession is a poor response to economic inflation since, for many areas, road maps need even larger scales than they once had. Complex interchanges between limited-access highways symbolized with squares or diamonds cannot suggest the decisions a motorist must make when confronted with bifurcating on- and off-ramps leading to several major roads and numerous city streets as well. These symbols sometimes imply that the driver has a choice, when this is not the case. An example is the interchange of Interstates 81 and 690 in Syracuse, New York (Figure 34). Even the inset maps for the city suggest that a motorist eastbound on I-690 can turn north onto I-81 without leaving the expressway system. This transfer is impossible, as is a direct exit from I-81 southbound onto I-690 westbound. The confusion, agitation, and possible traffic hazards resulting from this and similar map portrayals argue for the use of larger scales and symbols that call attention to impossible routings.

Some problems of route following, of course, are beyond the capacity of the map. Very complex interchanges, for instance, cannot readily be interpreted by the map reader if represented by equally complex mapped patterns. Highway signs, another important type of symbols, can be used to alert the motorists to potential dangers and to enable them to maintain their intended routes. In this case, the scale is 1:1 and the map is reality rather than a reduced representation of the Earth. Prominent signs are needed, nonetheless, in this full-scale environment. The locating of these signs might be made more effective if there were closer cooperation between highway engineers and map makers.

City street maps constitute another class of road map. Their scale is larger and they are sometimes accompanied by a street guide that indexes both streets and blocks. Since these maps intend to provide much more complete locational informa-

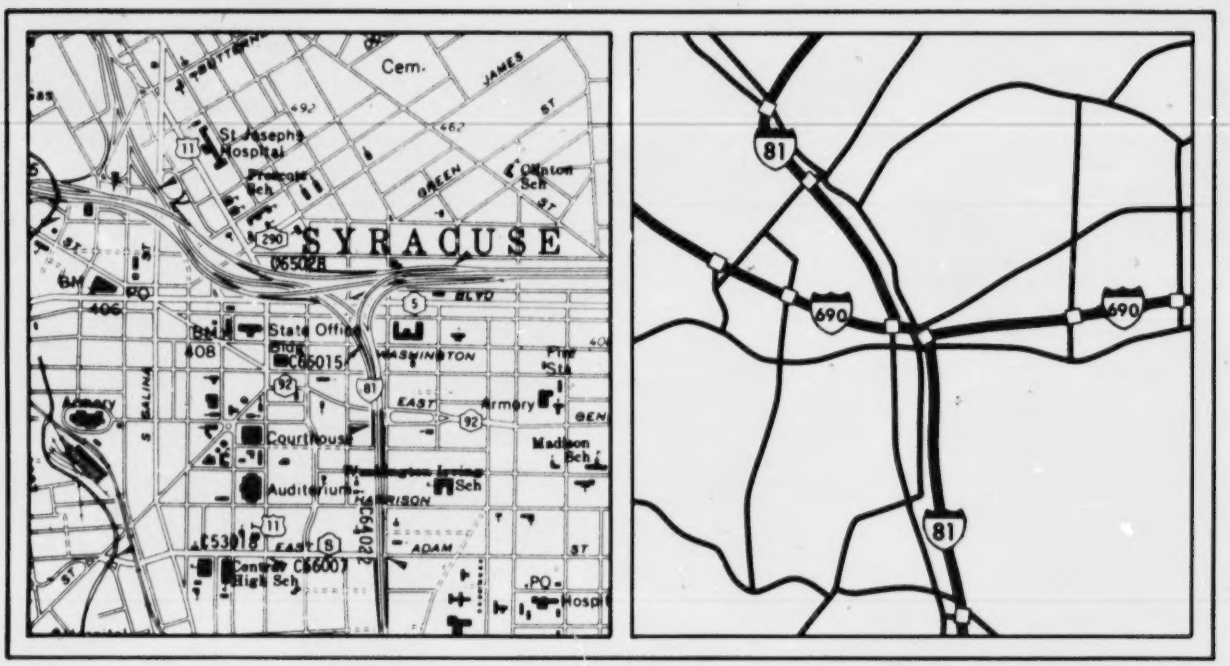

Figure 34. Intersection of Interstates 81 and 690 in Syracuse, New York. Source: New York State Department of Transportation, 1:24,000 Syracuse West Quadrangle, 1973 (left); copied with permission. Map at right is generalized from city insets on highway maps produced by several different publishers.

tion, they must not be as generalized as highway maps. Even though the design of a street map is, as a result, less demanding, many street maps are inadequate because readers are not provided with important landmarks, such as monuments, corner properties, stores, and shopping centers, that are frequently used when directions and locations are communicated verbally. Moreover, some office buildings and shopping plazas that are used as addresses by the Postal Service and the Yellow Pages cannot be located on the map! The mental or cognitive sketch maps (Lynch, 1960: Downs and Stea, 1973; Wood, 1973; Gould and White, 1974) of persons newly acquainted with an area might be used by map makers to determine what landscape features would be most helpful as visual cues to prospective users of a street map.

Another difficulty sometimes arises when map publishers obtain their information about the street network from the city engineer's office and do not bother to field-check their data. Engineering maps are intended to show rights-of-way and occasionally include *paper streets*—roads planned, but never built. On a street map, however, paper streets are seldom more than curiosities, and can be quite misleading (Figure 35). The appearance of paper streets on maps sold to the public points out, nevertheless, that a map designed for one purpose should not be used for another without a careful examination of its relevance to the second objective. Therefore, drivers of emergency vehicles are required to know their area first-hand, not its map!

Whereas street maps require including all streets within the area mapped, special purpose maps may show only selected streets. Furthermore, if distance relationships are not particularly important to the goal of the map, as in the case of public transportation routes, a schematic representation of only relevant roads will not only suffice but also be desirable since greater detail can be shown where needed. Schematic maps of bus routes, therefore, require only those streets along the route, although important cross streets and landmarks give the traveler a useful geographic frame of reference (Figure 36). Relatively long sections of the route along the same street can even be abridged, thereby allowing additional space for route numbers and more complex parts of the route. At a time when the public is being encouraged to make greater use of public transport, it should not be unreasonable to assume that the user is already familiar with the streets in the vicinity. The average transit patron needs only to know where the bus line is—the individual stops are often indicated by roadside signs—and which route goes where. This rationale is also applicable to railroad and airline passengers who are interested in the sequence of stations or direct connections rather than in other characteristics of a route. Scale distortion on schematic maps is consistent with their purpose and increases their effectiveness.

Figure 35. Example of a paper street. Note Cumberland Avenue running north-south at the center of the city planning map (right); the segment within the inner border is absent from the map the state prepared from aerial photographs. Source: New York State Department of Transportation, 1:24,000 Syracuse East Quadrangle, 1973 (left) and Syracuse and Onondaga County Planning Agency, 1:12,000 map of Syracuse, New York, 1968; copied with permission.

Maps for Data Processing

In the same way that highway and street maps for planning and following routes require a design and content suited to their human users' needs, some maps of city street networks demand information and a format tailored to the requirements of a mechanical "user," the computer. Computer-oriented maps are used by the Bureau of the Census to describe the geographic arrangement of street addresses, census blocks, and census tracts. The data from individual census questionnaires returned by mail to the Bureau must be accumulated for blocks, tracts, and larger areas in compiling summary reports for the decennial (and eventually the quintennial) Census of Population and Housing. The computer, linked to a system called FOSDIC (for Film Optical Scanning Device for Input to Computers), is able to read the circles blacked-in by the respondent and to record the results on magnetic tape for further processing. Because the computer also prepares counts for geographic units, it needs an easily read map containing both street addresses and area codes. Although optical scanners can read filled-in circles on the returned questionnaires, the map is more useful to the computer if it is already in machine-readable form on magnetic tape and if geographic information is coded with computer processing as the map's primary goal.

This map, called a *geographic base file*, is rooted in the Bureau's subdivisions of urban areas. The most frequently used subunits are the census tract, a relatively homogeneous area containing an average of 4,000 people, and the block (Figure 37). Tabulations are published for both of these small areal units. Each block belongs to a tract and is bounded by street segments or other linear features, such as streams, railroads, and political boundaries. Each street segment is bounded by two intersections and, except for some short, dead-end streets, separates one block from another. Between the two intersections the street has a range of odd- and even-numbered addresses, which, in the tabulation process, must be related to the appropriate block and tract numbers. These linkages among blocks and address ranges are the essential data for an Address Coding Guide. If, however, the geographic base file is also to be used for computerized mapping, geographic coordinates can be supplied for the intersections.

The basic elements of the file are intersections, street segments (or portions of other linear features), and blocks (Figure 38). Their structure can be described by a *linear graph* of *nodes*, *edges*, and *circuits* (chains of edges surrounding an area). These elements of a graph have 0, 1, and 2 dimensions, respectively, and are also called *0-cells*, *1-cells*, and *2-cells*. A cell with n dimensions is *bounded* by other cells with $n - 1$ dimensions. For example, two points, each with 0 dimensions be-

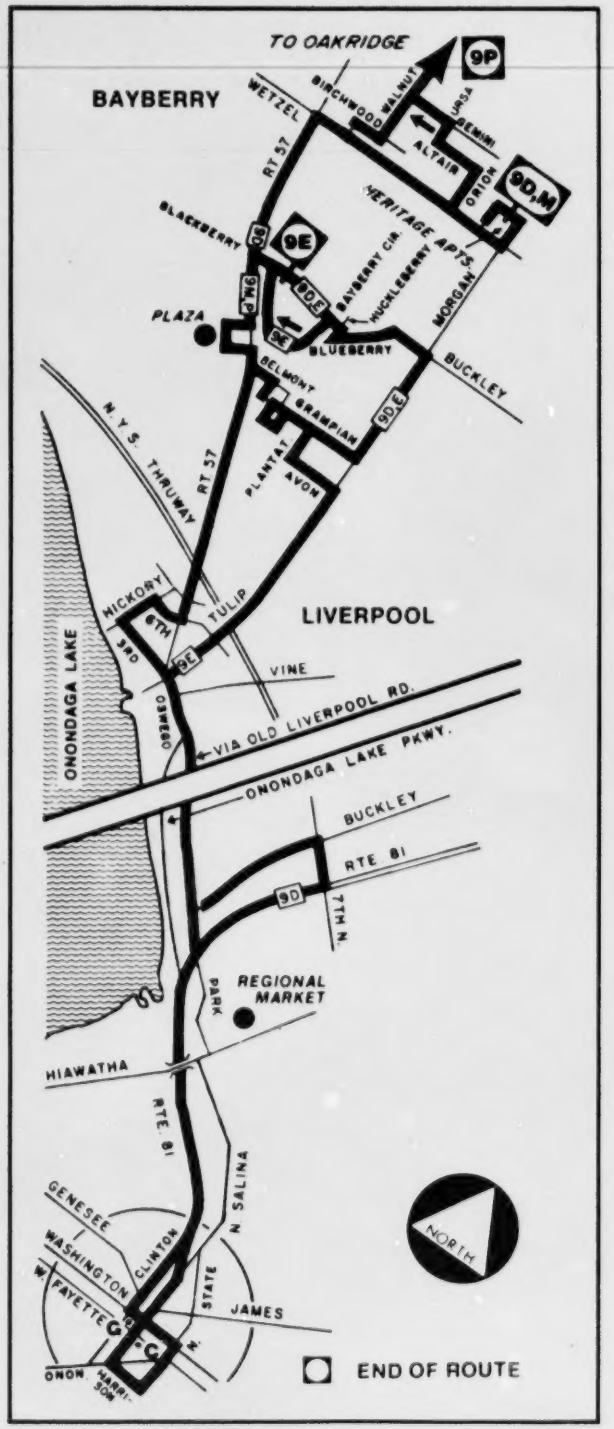

Figure 36. A schematic bus-route map. Source: Central New York Transportation Authority, 1976, Liverpool-Wetzel Rd. schedule; copied with permission.

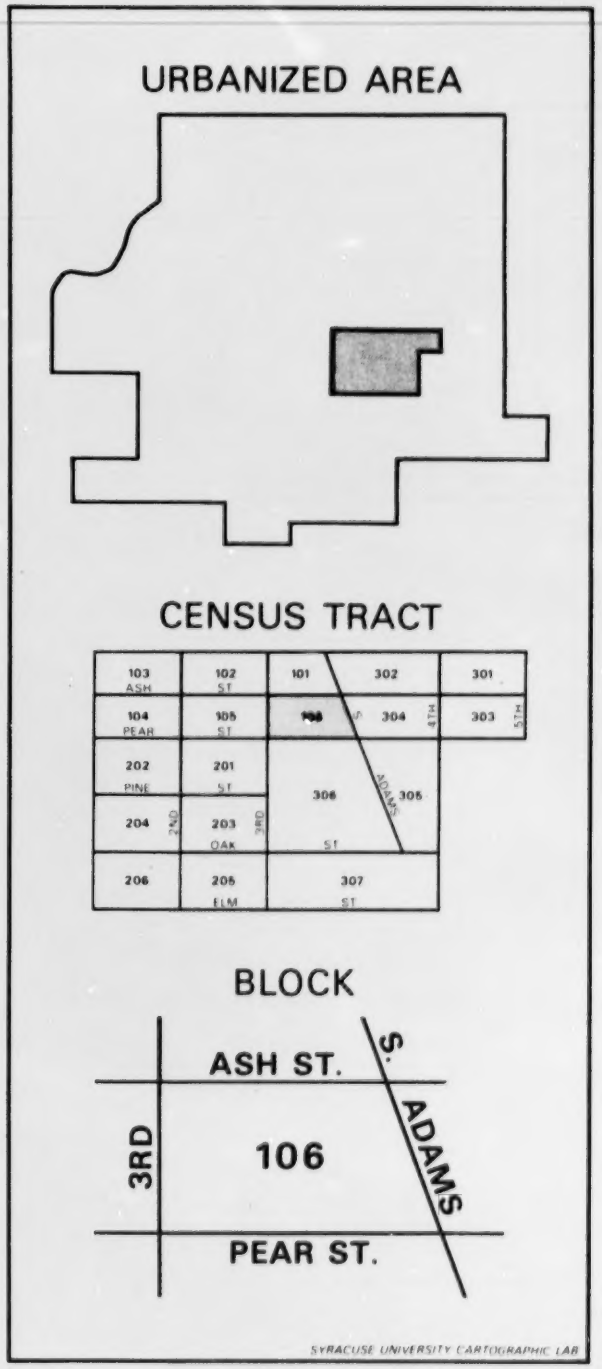

Figure 37. Census subdivisions of an urbanized area.

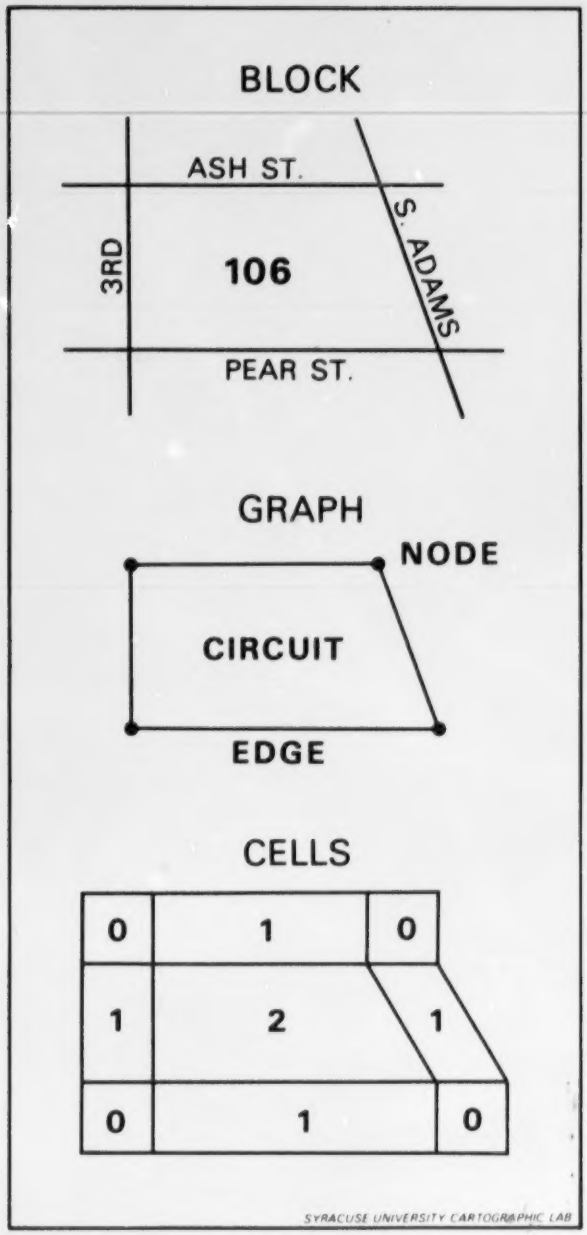

Figure 38. A census block as a linear graph and an assemblage of 0-cells, 1-cells, and 2-cells.

cause they have no length or area, delimit a line segment which has only 1 dimension, its length. Similarly, 2-cells are bounded by 1-cells. Furthermore, cells of $n + 1$ dimensions are said to *cobound* a cell of n dimensions, when, for example two adjacent 2-cells cobound the 1-cell between them (Corbett, 1975).

Since each boundary segment around a block can be identified by the nodes that bound it and also by the cobounding blocks to its left and right, a file structured on the basis of these linkages is called *dual independent*, and the Census Bureau's geographic base file is named DIME for Dual Independent Map Encoding (U.S. Bureau of the Census, 1970:5-7). A DIME record (separate entry in the file) represents an individual segment of a street or other linear feature and includes the segment's name or description, the numbers of the nodes bounding the segment, and the codes of the cobounding blocks (Figure 39). Moreover, the left and right street address ranges, census tract codes, and codes for other types of administrative areas are usually included. Thus, the file contains all the information needed to determine which street segment and which block include a specific address.

Given this information, a computer can not only associate street segments with blocks but also scan the file to determine 1) those blocks bounded by a larger circuit of linked street segments or 2) those blocks along a route between two distant nodes. Furthermore, block codes can be matched with the census counts for individual blocks, and as a result, census data can be reaggregated for irregularly shaped school districts as an aid in evaluating court-ordered desegregation plans, and persons easily can be assigned to nearby fallout shelters with limited capacities. This latter application uses the geographic coordinates supplied for the nodes to calculate the lengths of different street segments. Since DIME is also an Address Coding Guide, employees' addresses can be matched to facilitate carpooling. DIME's ability to link addresses with census data and codes for other administrative regions has numerous uses in transportation planning, health-care-facility location studies, and the analysis of traffic accident locations, to name a few less apocalyptic projects that have been undertaken (U.S. Bureau of the Census, 1973:29-37). This machine-readable map, in addition to assisting automated spatial analysis without the use of printed maps, can also be used for computer-produced maps based on census data or phenomena recorded by street address, such as crimes, accidents, births, and the locations of hospital patients (U.S. Bureau of the Census, 1969). Eventually, computer-oriented map files covering larger areas might even be employed in the automated production of Triptiks and other personalized maps and atlases! The continued development, updating, and distribution of DIME and other geographic base files should enable planners, map makers, and researchers in general to take even fuller advantage of the computer's speed and accuracy.

Advocacy, Research, and Mapping

Most maps are intended for humans, not computers. Although maps prepared to communicate the results of research are usually concerned with increasing the reader's understanding of a topic, researchers sometimes want to spur at least a fraction of their audience to more direct action. Force-

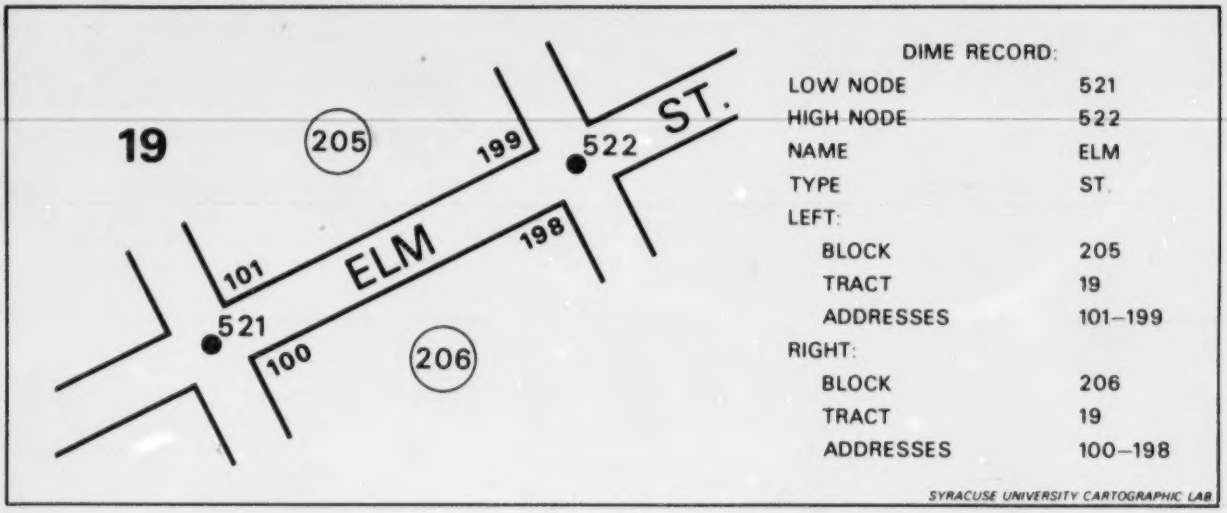

Figure 39. Representation of a DIME record.

ful maps, like compelling writing, can play a vital role in convincing an apathetic public that a problem exists and that a society and its government must act.

Since health, as a major component of human well-being, has a spatial dimension, it is not surprising that advocates of change have used maps to identify for themselves and others important relationships between illness and geography. In 1848, for example, Dr. John Snow, a general practitioner in London, was concerned about a major outbreak of cholera. He mapped the residences of victims and noticed that their homes clustered around a pump to which they walked for drinking water. His map of the area around the Broad Street Pump (Figure 40) was important in medicine's understanding of the waterborne transmission of cholera. Snow removed the pump's handle and soon thereafter new cases of the disease ceased (Stamp, 1964:15-16).

Although Snow was able to act directly by removing the pump handle, in modern society complex technology and an equally complicated political-economic structure have produced intricate problems and bureaucratic buffers. Inferences and theories believed to be solutions cannot be tested easily by individual initiative, and often appeals must be made to influential groups of scientists and public leaders. An example is Sternglass's thesis that radioactivity from nuclear weapons testing and, more recently, nuclear reactors and fuel processing plants, contributes to infant mortality. Sternglass, a professor of radiation physics at the University of Pittsburgh, was aware that even small doses of strontium 90 can cause genetic damage in animals. He also knew that around 1950 there was an inexplicable departure from the continuing decline in the infant mortality rates of the United States and other developed nations—an established downward trend that began as far back as 1900. The interruption of this trend coincided with increased atmospheric testing by the United States and the Soviet Union, but the downward trend resumed after these nations halted nuclear testing in the atmosphere! Sternglass (1969) documented his arguments with graphs of mortality plotted against time. When the trend for actual infant death rates

Figure 40. John Snow's map of cholera deaths in the vicinity of London's Broad Street Pump (from Stamp, 1964:16). Reprinted by permission of The Athlone Press of the University of London.

was compared with that for rates extrapolated from trends for years prior to 1945, the vertical differences between the two lines provided a measure of excess infant mortality. Although critics questioned Sternglass about his extrapolation methods, his maps showing the geographic distribution of excess infant mortality present a forceful argument. One set of maps shows the association between excess mortality and an atomic test site in New Mexico (Figure 41). Although no discernible geographic trend was evident for 1946, one year after the test, by 1950 excess infant mortality was concentrated in a belt east of the test site in the direction of movement of the prevailing westerlies and the radioactive cloud. He attributed an anomaly in North Dakota to the high level of strontium 90 in milk sold there. Sternglass has also prepared maps relating excess infant mortality to the locations of nuclear energy plants—an association that has generated a heated, and as yet unresolved, controversy.

Geographers have also been interested in threats posed by technology and have used maps in presenting cases against the pollution of the physical and social environments. Their understanding of cartographic communication's potential has led to maps as radical as their own ideas and life-styles. An excellent example is William Bunge's "base map for survival," which directs the reader's attention specifically to the distribution of the world's children (Figure 42). Bunge (1973) was deeply concerned with the possible extinction of mankind by "machinekind" and thought that people, not property or territory, should be emphasized on a world map. His assertion that this is the base map that should be taught in the classroom is a clear recognition that people's attitudes are influenced by impressions of reality received from maps.

Maps and Advertising

A less idealistic advocacy has an important place in the economy, where vendors compete with each other for the public's attention. Although this might seem an invidious comparison, maps used by advocates of business in their advertisements surpass in number and effectiveness the maps of advocates of social change. Graphic artists employed by advertising agencies and their often elaborate studios produce maps that attempt to convince consumers of the merits of particular products or services. Color printing is used effectively, but, except perhaps for placemats touting a restaurant chain's numerous locations—and the possibility of a profitable franchise in your own town—innovative designs are needed to attract the interest of sated readers bombarded with a wide variety of visual stimuli by advertisers in major popular periodicals. "Creativity" has become a principal objective of advertising; hard sell and the straightforward providing of information are no longer adequate. The result, for mapping, has been the development of many ideas that might be borrowed by researchers concerned with the more effective selling of their findings and theories.

Not all maps used in advertisements, of course, are attention-getters, nor are they necessarily useful. The ordinary how-to-get-there map, does convey useful information but usually excites little interest. As in published research, many advertising maps are employed peripherally as window dressing, drawing little attention to the advertiser's message, possibly contributing an impression of accuracy or importance, and usually serving as convenient "fillers." Other advertising maps, however, are meaningful distortions of space consistent with and enhancing the seller's message. Continental Airlines, as an example, uses a map in the center of an advertisement, directly below the message "We've got connections" in bold type. Their map not only shows the cities they serve in Hawaii and the continental United States but also shows Hawaii, at an enlarged scale for greater emphasis, much closer to the mainland than it would otherwise appear

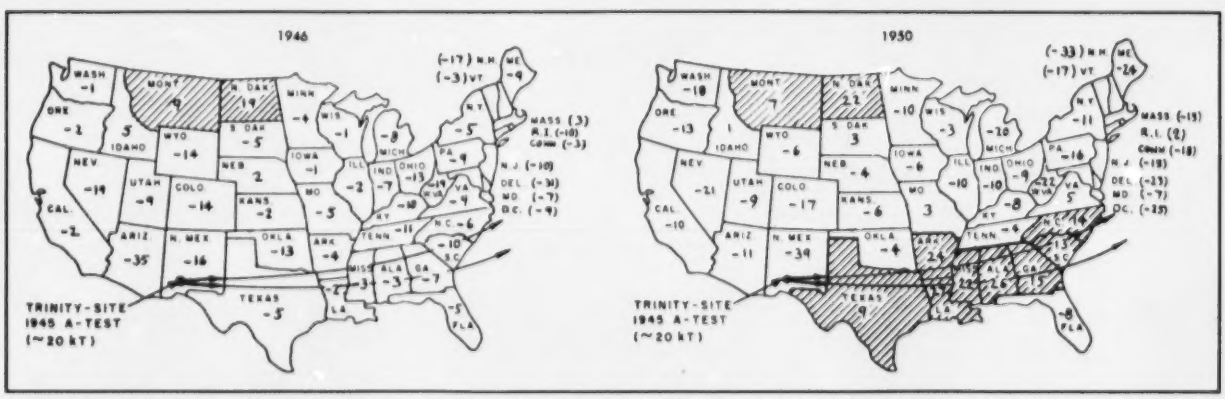

Figure 41. Sternglass's maps of the association between excess infant mortality and a New Mexico atomic test site (from Sternglass, 1969). Numbers are percentage changes in infant mortality rates relative to rates obtained by projecting forward trends for 1940 to 1945. Reprinted by permission of the *Bulletin of the Atomic Scientists*.

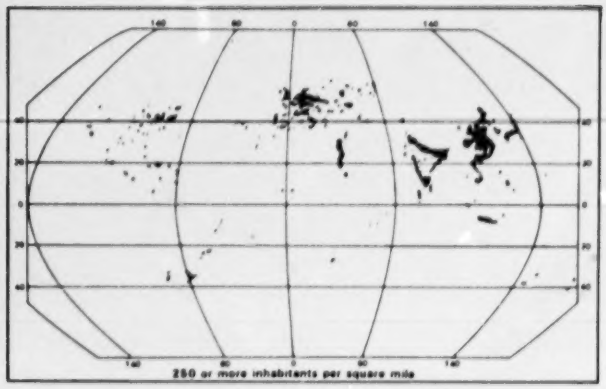

Figure 42. Bunge's map of the islands and continents of the world's children (from Bunge, 1973). Reprinted by permission of the Association of American Geographers.

(Figure 43). The map completes the message: Continental's connections put you, the passenger from Lubbock, closer to Hawaii. The shortening of route distances is used effectively by other common carriers, particularly those serving resort areas.

Numerical superiority is another common theme. The chain with the most pizza shops—see them all!—must make good pizza. This type of message can be transmitted more readily and make a more lasting impression, however, if pictorial symbols are used instead of dots. Steinway and Sons uses a map to demonstrate the dominance and superiority of their pianos (Figure 44). Its diminutive caption reads: "Of the piano soloists scheduled to play with major U.S. orchestras during the 1975-76 concert season, the great majority will play the Steinway piano." The names of the orchestras suggest prestige, but the intriguing map of little pianos, most of which are a bolder black representing Steinways, delivers the message.

Violation of cartographic tradition is another means of making the map, the advertisement, and the message obvious and clear. Marine Midland Bank wanted to announce that its regional subsidiaries had integrated their operations and that customers could now obtain its services at any branch in New York State. Its map of "the united state of Marine Midland" describes this merger in its title (Figure 45), but rotating New York so that north is no longer at the top serves notice that something new and different has occurred. In applications outside advertising, maps departing from the ordinary in projection, symbolization, and generalization might be more eye-catching and, as a result, surmount negative attitudes of the reader more effectively than the types of map normally used.

Information and Misinformation

However striking or authoritative a map might be, the reader must beware of maps that deliberately distort both reality and the truth. John K. Wright, in his paper "Map Makers Are Human," warned that, "The trim, precise, and clean-cut appearance that a well drawn map presents lends it an air of scientific authenticity that may or may not be deserved" (1943: 527). As applied to graphs, the same theme is discussed in Darrell Huff's (1954) readable and humorous little book *How to Lie with Statistics*. Also concerned with graphs, M. J. Moroney's *Facts From Figures* (1956) presents several examples of inadvertent or deliberate visual distortions of fact. Most of the English-language papers on cartographic deception, however, focus upon the propaganda value of maps and were written, not surprisingly, during or shortly after World War II. Quam notes that a map ". . . designed to produce impressions rather than to reveal information . . . becomes

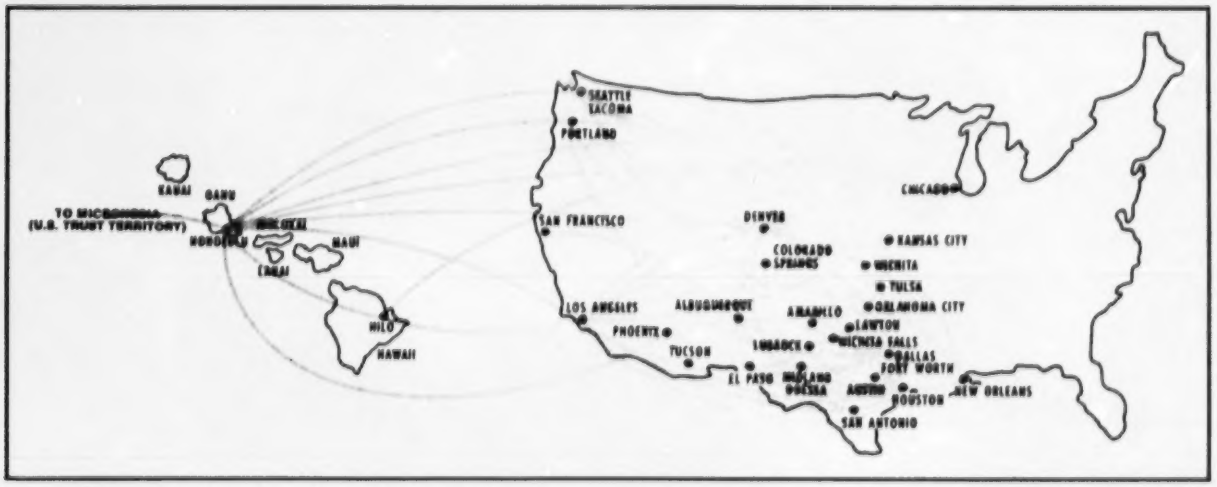

Figure 43. Map from Continental Airlines' advertisement "We've got connections" (courtesy Continental Airlines).

Figure 44. Eastern portion of Steinway piano map (courtesy Steinway and Sons).

a psychological force instead of a scientific tool" (1943:21). The map's power of impression for the sake of oppression was condensed to a single word, "Cartohypnosis," the title of a paper by S.W. Boggs (1947), a geographer with the U.S. Department of State, who paid particular attention to how the Nazis used maps for propaganda. This subject is treated more fully in Hans Speier's (1941) "Magic Geography." The American press, although its motives were less sinister, was not above printing what Ristow (1957:385) termed "suggestive" maps to dramatize military operations by using clamps, pincers, sickles, nets, bomb-burst symbols, and the like. Yet, motives aside, we cannot fault many of these maps for their graphically purposeful layouts and symbolization.

How do maps serve as propaganda? Between 1939 and 1941 the German Library of Information published *Facts in Review* from its offices in New York City. This slick weekly occasionally supplemented its text and photographs with maps in attempts to win support for the Third Reich by pandering to American nationalism. A graphic attempt to persuade Americans to keep to their own backyard appeared in the April 10, 1941 issue (Figure 46). Here the black areas on the map represent "the four principal industrial centers of the world," whereas "Food and raw material producing areas are shaded." The bold boundaries highlight "spheres of interest" to suggest that the United States' domain was confined to the Americas. This is but one example of authoritative-seeming boundaries used to influence opinion.

The military also employed maps as important elements of cover plans to deceive the enemy before major battles. During World War I, the British "lost" a canvas bag containing maps and other documents near Beersheba during a brief exchange with a Turkish patrol. These documents convinced German and Turkish intelligence officers that Allenby's forces would attack at Gaza in late November 1917. In late October the British also established a main camp opposite Gaza to be photographed by Turkish reconnaissance planes. The British withdrew most of these troops during the night of October 30 and, the next morning while the Turks were shelling the British trenches at Gaza, the main British forces attacked at Beersheba and prevented the destruction there of the walls needed for further advances by the Desert Mounted Corps (*Army*

Figure 45. "The united state of Marine Midland" (courtesy Marine Midland Bank.)

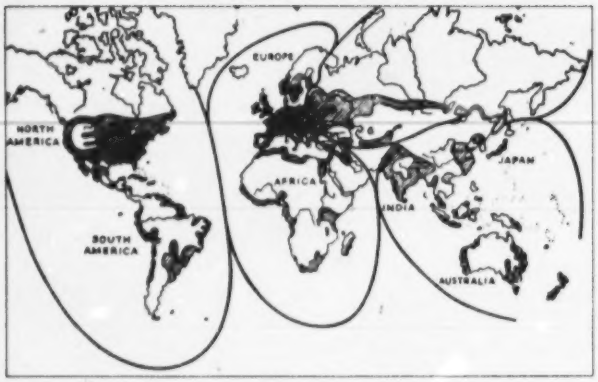

Figure 46. Spheres of influence on a Nazi propaganda map (from *Facts in Review*, 10 April 1941).

Times, 1963:76-89). The Allies also planted deliberately falsified maps during World War II, but these deception plans required elaborate supporting evidence in order to dupe Hitler's officers. As with propaganda maps, their specific influence is often difficult to assess.

Deliberate errors have also been noted on Soviet maps by Ormeling (1974:48-49) who contends that misrepresentation of the locations of cities and boundaries as well as the use of erroneous hydrographic data cannot be ascribed to technical error. The Soviets apparently decided to alter the positions of coastlines, rivers, towns, and railways between the last printing of their world atlas in 1964 and its second edition in 1967. Distortions have been noted in both strategic and nonstrategic areas, and their map projections have also been inconsistent. However, the presumed military value of this expensive program of deception is questionable because far more exact geographic information can be obtained by intelligence-gathering satellites (*New York Times*, 1970). These distortions and those of propaganda maps cannot usually deceive an informed reader. Nevertheless, their existence should serve to warn inexperienced readers that maps can be used by their authors to tell black as well as white lies.

VI. CONCLUDING REMARKS

The theme of this Resorce Paper has been that maps *must* distort. Since the term "propaganda" was originally contrived in the seventeenth century to mean "spread the faith," many maps, especially thematic maps, are propaganda maps. A map's distortion of reality is evil only when its author's purpose is malevolent. In the more common use of the term, most propaganda maps are quite effective graphics because their authors knew what they wanted to say and how to say it with maps. Their symbolization and classification are simple, direct, and interesting.

Map authors sincerely interested in effective cartographic communication need only a formal awareness of their message, an appreciation of the limitations imposed by the map reader's attitudes and visual sensors, an understanding of the elements of maps, and the common sense and initiative to integrate this knowledge. A message too complex for an average reader might be made more acceptable if simplified into two or more manageable themes. Use of uncomplicated, visually striking symbolization might make a blasé reader pause long enough before turning the page to appreciate and decode the map. Careful choices of data and projection and the use of graphically logical generalization and classification might lead the reader to the desired interpretation and response. Unconventional cartographic practices might be made to serve traditional mapping needs.

Writers, of course, obviously cannot cater to illiterates, and map authors should not be inhibited by totally unprepared or indolent map readers. A society priding itself on the educational opportunities it offers ought not to ignore its duty to educate people to want to read both books *and* maps. Penalties accrue to the untrained map reader unaware of the existence of a potentially useful map. The graphically inept map user might not only be unable to ferret out needed information, but might also be the victim of self-deception by inferring a meaning wholly unrelated to that intended by the map author. For a motorist or soldier the penalty might be death or injury; for a society with graphically naive planners and politicians, the price might be an economic or aesthetic disaster. Even map readers with needs no more sophisticated than route following should be spared a lost innocence.

Map use cannot be effortless. Many maps—particularly general as opposed to thematic maps—cannot and should not be distilled into useless sheets of paper for the graphically lazy. Mapped information, like other information, achieves meaning only when the user is both able and willing to study the map. Although map makers should strive for clarity, their goal should be to inform—not to seduce. Both map reader and map author have active rather than passive roles in cartographic communication; both should attempt to understand the communication process; both must strive to make it effective.

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